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OLFACTORY ACUITY IN SELECTED ANIMALS CONDUCTED DURING THE PERIOD JUNE 1972 - SEPTEMBER 1974

Southwest Research Institute

Prepared for:

Army Mobility Equipment Research and Development Center

September 1974

INTERIM TECHNICAL REPORT ON OLFACTORY ACUITY IN SELECTED ANIMALS CONDUCTED DURING THE PERIOD JUNE 1972 - SEPTEMBER 1974

Submitted to
Mine Detection Division
Countermine/Counter Intrusion Department
U. S. Army Mobility Equipment
Research & Development Center
Fort Belvoir, Virginia

The data summarized herein was developed under
Contract No. DAAK02-72-C-0602

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO CORPUS CHRISTI HOUSTON

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ACKNOWLEDGEMENTS

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Furthermore, the present investigation could not have been successfully concluded without the unusual devotion and extraordinary personal commitment to program goals demonstrated by Dr. David F. Culclasure, Dr. Daniel S. Mitchell, Mr. James J. Polonis, and all members of the training staff at Southwest Research Institute.

INTRODUCTION

This report summarizes the results of extensive experimentation designed to assess the olfactory acuity of various animal species for commonly encountered explosive odors in tactical situations such as C-4, Composition B, TNT, tetryl, PETN, and RDX. The experimental population included various breeds of canines as well as more exotic animals such as the domestic pig, javelina, coyote, civet cat, fox, raccoon, skunk, coatimundi, deer and ferret. In approaching this task, which had as its aim identification of potentially effective biosensors, both laboratory and field assessments were utilized. The latter approach (field assessment) was considered to be particularly important in that it represented conditions under which the biosensor would ultimately be used. Following are photographs of several of the animals utilized in the research.

FIGURE 1. Shown above with their handlers are four of the exotic animals appraised for potential biodetectors for explosive odors. First in line is Sherlock, a silver fox; next is Rosie, a javelina; then Greta, a domestic pig; and last is Wiley, a coyote.

FIGURE 2. Silver fox being rewarded for detecting an uncovered mine during the early stages of field training. In subsequent stages, the mine is covered and camouflaged to minimize the presence of visual cues.

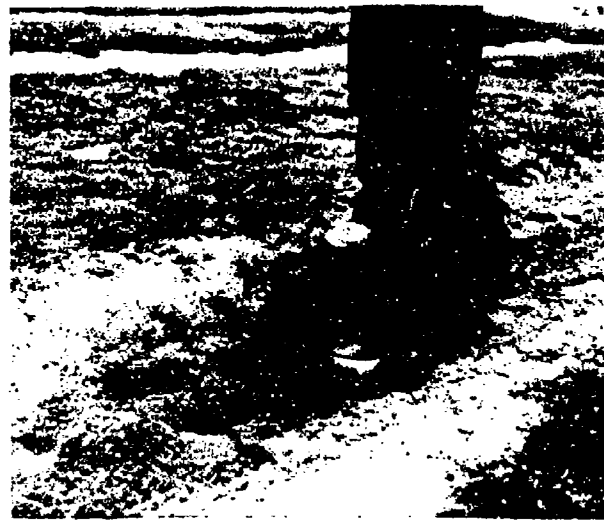


FIGURE 3. Javelina detecting partially buried explosive sample. As training progresses, the sample is completely buried up to depths of 12 inches.

FIGURE 4. Coyote detecting an anti personnel mine placed on the earths's surface. The mine is activated by a trip wire.

FIGURE 5. Skunk searching for buried explosive on practice mine lane.

FIGURE 6. Greta, a red duroc pig, being rewarded with corn after sitting to indicate detection of a buried explosive.

FIGURE 7. Rosie, a javelina, being rewarded with a piece of food after sitting to indicate the presence of a buried mine.

FIGURE 8. Slinky, a ferret, demonstrating the indicant response (standing on hind legs) used to signify the location of a concealed explosive.

FIGURE 9. Young deer used in the olfactory sensitivity study. While it was shown that the deer had an exceedingly good sense of smell, difficulty in training the animal to search reliably prevented continuation of the deer in the biosensor program.

FIGURE 10. Genetic miniature pigs evaluated under the olfactory sensitivity program. These miniatures grow only about half as large as the typical domestic pig.

FIGURE 11. The coatimundi was demonstrated to possess a keen sense of smell. However, his lethargic nature precluded effective use as a biosensor.

FIGURE 12. The raccoon was shown to possess a very keen sense of smell; and, although the research staff was successful in reversing the animal's normal (nocturnal) diurnal cycle, behavioral considerations precluded effective use as a biosensor.

EXPERIMENTAL APPROACH

To obtain the desired information concerning the olfactory acuity of the animals specified earlier, an overall experimental strategy was developed which consisted of three major phases:

Phase I. Laboratory and field training on surrogate land mine detection problems

Phase II. In-laboratory odor-component analysis

Phase III. Determination of the relative sensitivity (threshold) of various species with regard to the detection of surrogate mines.

Phase I.

Phase I consisted of standard conditioning and discrimination training procedures in which the animals initially were conditioned in the laboratory to make an appropriate alerting response (e. g., sitting down) in the presence of the composite odor of a surrogate land mine. A variety of potential surrogate land mine models were considered. However, the design described below (and shown as Fig. 13) was selected for use. The design consists of a covered glass Petri dish approximately 3-1/2" in diameter into which may be placed all or any combination of the odor elements of interest. For example, during laboratory studies a "composite mine" can be simulated by introducing predetermined quantities of explosives, metal filings, and soil into a sterile Petri dish, followed by appropriate handling to impart the element of human scent.

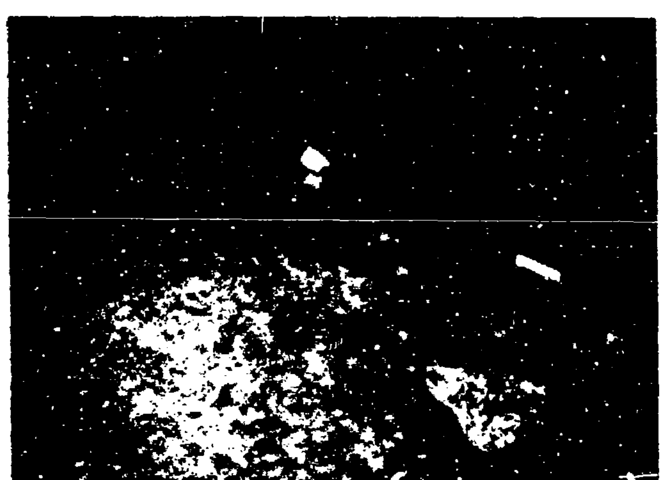


FIGURE 13. Surrogate land mine consisting of a Petri dish, C-4, TNT, and iron filings

Upon mastery of the laboratory detection task described above, the animals were then advanced to field search and detection problems involving simulated battleground conditions. Detection performance of each species was assessed under both the laboratory and field environments.

Phase II.

The primary objective of Phase 2 of the study was to determine which, if any, of the four major odor components of the surrogate land mine (explosive metal, human scent, soil) serves as the primary cue in olfactory detection. The experimental attack on this problem consisted of several successive stages:

(1) Asympotic discriminative instrumental reward conditioning with continuous (100%) reinforcement in which the discriminative stimulus (S) consisted of an odor composite comprised of the four basic components of interest (explosive, metal, human scent, and soil).

(2) Continued training to the odor composite following a shift from the continuous to a partial reinforcement schedule, the latter introduced in order to insure high resistance to extinction of the alerting response on subsequent test trials.

(3) Introduction of intermittent "test trials" on which separate components of the composite odor were presented alone. An index of the relative role of each of the four odor components was then obtained by computing percentages associated with the animal's responding to each of the individual components.

(In order to preclude spurious <u>over</u>-estimation of level of responding to the separate components due to the gradual accrual of associative strength, test trial responses were not reinforced. The potential problem of spurious <u>under</u>-estimation of level of responding to individual components as a result of extinction via nonreinforcement was felt to be largely offset by the high resistance to extinction attending introduction of the partial reinforcement schedule.)

Phase III.

Phase III involved an experimental determination of the relative sensitivity or "threshold" of various species with regard to the detection of surrogate and actual land mines buried in both a homogeneous and heterogeneous media. For these purposes, "threshold" was defined as the maximum depth in inches at which a given animal can just reliably detect the presence of a composite mine.

Three mine lanes were constructed for the burial of simulated and actual land mines. (See Fig. 14) Each lane measured 2' wide x 2' deep x 75' long and was filled with common sand— thereby allowing the planting of surrogate or actual land mines (and control targets) at any desired depth up to a maximum of two feet below the surface. Lanes were designed to be used during the early stages of field search and detection training as well as during the "threshold" (depth of detection) phase of experimentation. The lanes had the advantages of permiting quick implantation and removal of targets and controls and allowing elimination (by mechanical raking or smoothing) of undesirable cues such as surface disturbances produced at the time of target implantation.

In addition to the mine lanes described above, a mine field matrix (Fig. 15) was constructed for use in later stages of training and evaluation. Laid out in an area of 200 yards by 200 yards, the minefield contained 100 targets (defused plastic mines, metal mines and controls) implanted at depths from 2 to 8 inches. The soil utilized was heterogeneous in make-up, featuring gravel, organic material and other soil constituents characteristic of south central Texas. The mine field featured a grid arrangement whereby animals could be introduced at randomly selected points within the field, so as to preclude any contribution of memory effects to the detection score. (Note: Animals have been shown to possess a remarkable memory for location and patterns. They easily memorize the precise placement of mines when allowed to run the same trail more than once in close succession.)

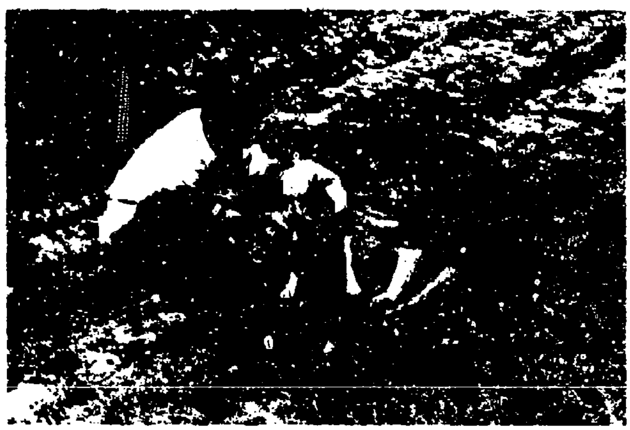


FIGURE 14. Three mine lanes filled with a homogeneous medium (common soil) for use in search and detection training.

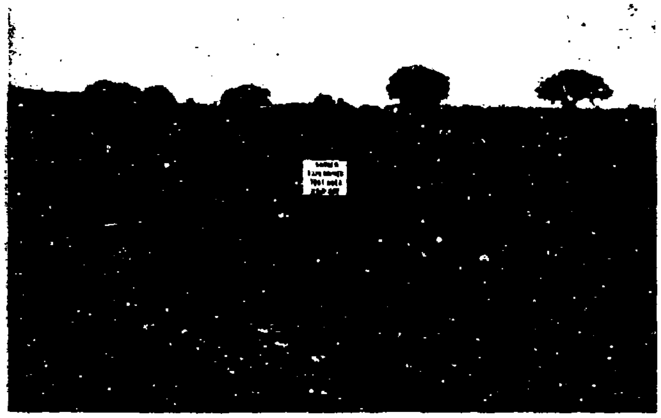


FIGURE 15. Mine field matrix consisting of 250 explosive targets and controls emplaced at various depths in a heterogeneous soil media. The mine field was used in later stages of training and evaluation.

Following is a pictorial sequence depicting how the experimental animals were taken through their various training tasks—from basic procedures designed to develop an appropriate indicant or alerting response to actual detection tasks performed on the mine field.

Step 1.

FIGURE 16. Animal being trained to "sit" as an alerting response. In this procedure, the food reward given for sitting is dropped when the animal becomes proficient in learning to associate the command "sit" with the action of sitting. The food reward is then used to shape the detecting-alerting-sit response triad.

Step 2.

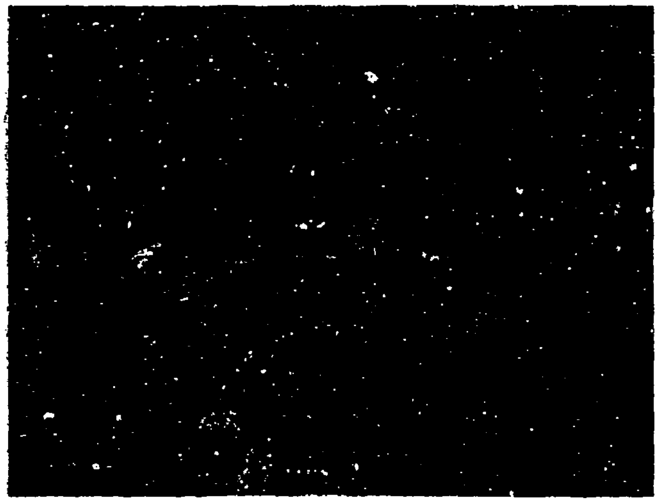


FIGURE 17. Animal being trained on target odor contained in a "positive" surrogate mine (petric dish). Later the discrimination of target odor contained in the positive surrogate mine versus two negative surrogate mines will be implemented.

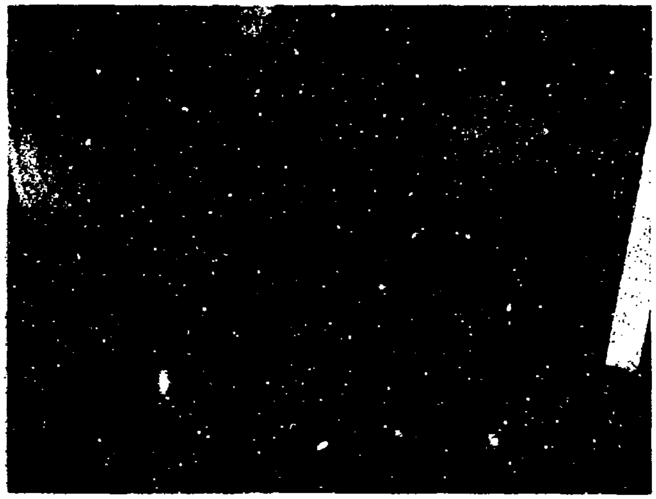


FIGURE 18. Animal making his indicant or alerting "sit" response after correctly detecting the target odor. It does not take long for the animal to learn to associate the sitting response learned earlier with the presence of the target odor. He rapidly learns to sit when the target odor is encountered during the training exercises.

Step 3.

FIGURE 19. The animal is next moved on to surrogate mine discrimination procedure. After proficiency has been developed, the animal then goes on to a three-surrogate discrimination procedure - from there to actual mines rather than surrogates and then to the mine lanes and mine field described earlier for intensive training in detecting mines buried at various depths.

In summary, the training regimen used consisted of initial odor training on the raw explosive, then graduating to a simpler procedure of initial training on a deactivated, fully loaded mine in a three-choice discrimination procedure. Once this had been performed to satisfaction, the animal was taken outside for training on the mine lanes, using procedures similar to those described above. Distractions were introduced at appropriate intervals, thus preparing the animal for detection work on the actual mine fields where both visual and auditory distractions prevailed.

After successful completion of intermediate training on the mine lanes (which featured a homogeneous overburden - sand), the animal was taken to the mine field and worked until he became proficient in detecting mines buried to depths up to 8 inches. From this point, the animal was deemed to be ready to go on to train, road and village search sequences. However, these search scenarios were not part of the required contractual effort.

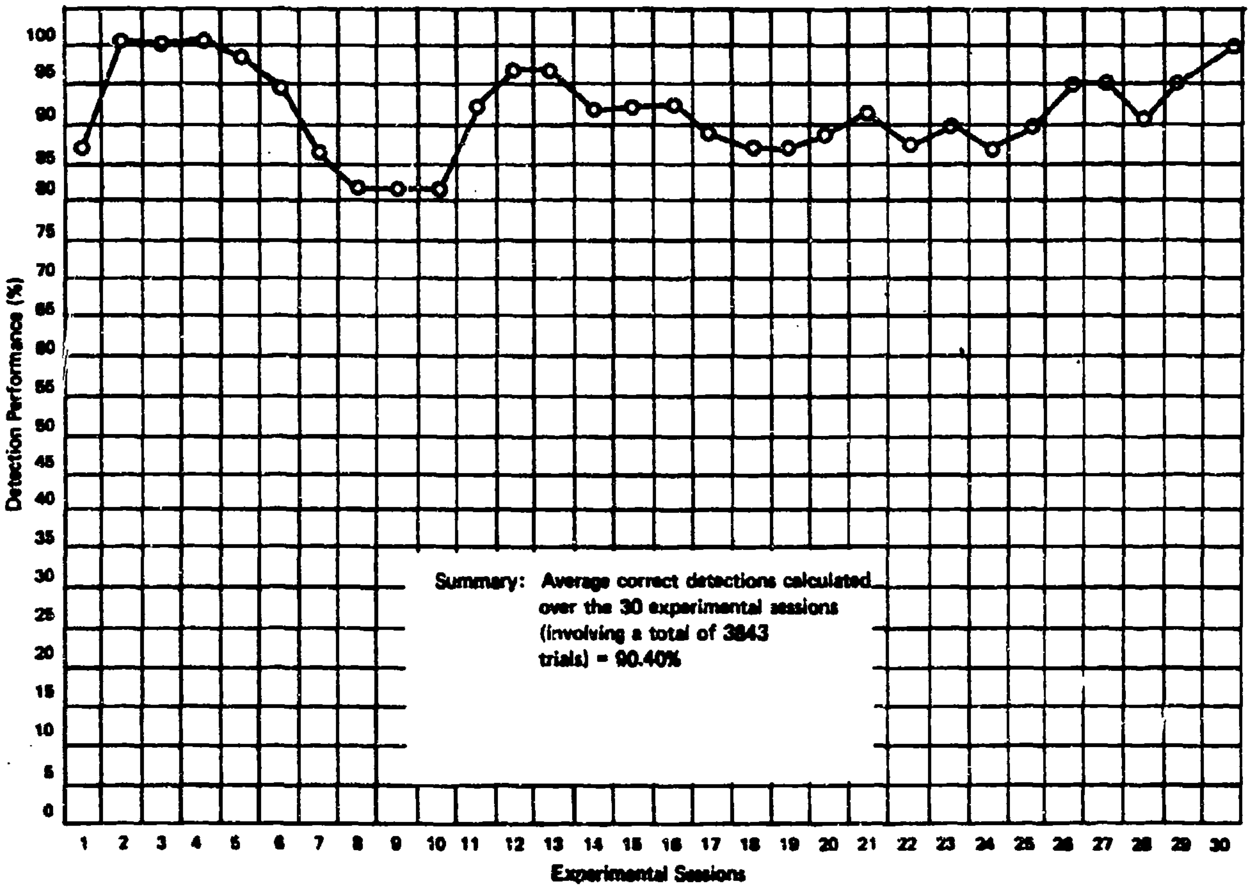
RESULTS OF OLFACTORY SENSITIVITY EXPERIMENTS CONDUCTED WITH EXOTIC ANIMALS

In working with the exotic animals, the project staff was impressed with the olfactory acuity demonstrated by all species studied. It was the general consensus, however, that the demonstrated acuity would have been greater had it been possible to establish greater rapport with the "wild" animal species. Unfortunately, available project resources precluded expenditure of an adequate amount of time for the socialization process. This resulted in the exotic animal's detection performance probably being depressed by such factors as distractability, fear of new situations, and absence of an adequate animal/handler relationship. However, despite these drawbacks, when the performance of the exotic animals is viewed in toto, one is impressed by their skill in detecting explosive odors. In many cases, their ability equals or exceeds that demonstrated by canines under similar detection situations. Unfortunately, due to the small population of animals used, it is impossible to make any generalizations concerning the various species studied. However, the data accumulated does appear to clearly indicate that certain animal species—other than canines—do possess sufficient olfactory acuity to merit consideration as biosensors for explosive targets. The relative effectiveness of each of the exotic animal species studied—in terms of detecting various explosive targets—is shown in the following table.

Table I. Relative Standing of the Various Exotic Animal Species Studied in Detecting Explosive Targets

Animal Species	N	Overall % Correct Detections	Total Number of Trials	Maximum Effective Detection Depth
Domestic Pig (Red Duroc)	2	89.30%	6637	12
Domestic Pig (Miniature)	1	80.08%	3503	8
Silver Fox	1	80.63%	2854	6
Coyote	1	80.33%	2981	6
Ferret	1	87.05%	3614	6
Coatimundi	1	81.33%	4795	6
Skunk	1	90.40%	3843	6
Javelina	1	80.20%	4014	6
Raccoon	1	60.88%	3714	6

Following are graphic portrayals of the various exotic animals' progressive performance during the total training program. These portrayals are particularly interesting in that they demonstrate vividly the degree of variability encountered across the various species. For example, by referring to the individual performance plots, it can be observed readily that while the ferret is rather consistently good in detecting explosive targets, seldom dropping below the 90% correct detection rate, other animals—such as the javelina—are exceedingly variable, fluctuating from almost perfect detection (100%) to a detection rate of under 50% correct detection. This is valuable information since, unless a biosensor shown to possess exceptional olfactory acuity can be counted on to display it consistently, its value under operational conditions is substantially negated. To what extent such demonstrated variability is amenable to remediation by intensive socialization and training programs is not presently known; it is, however, a matter that should be addressed in future research and development programs involving the use of biosensors.

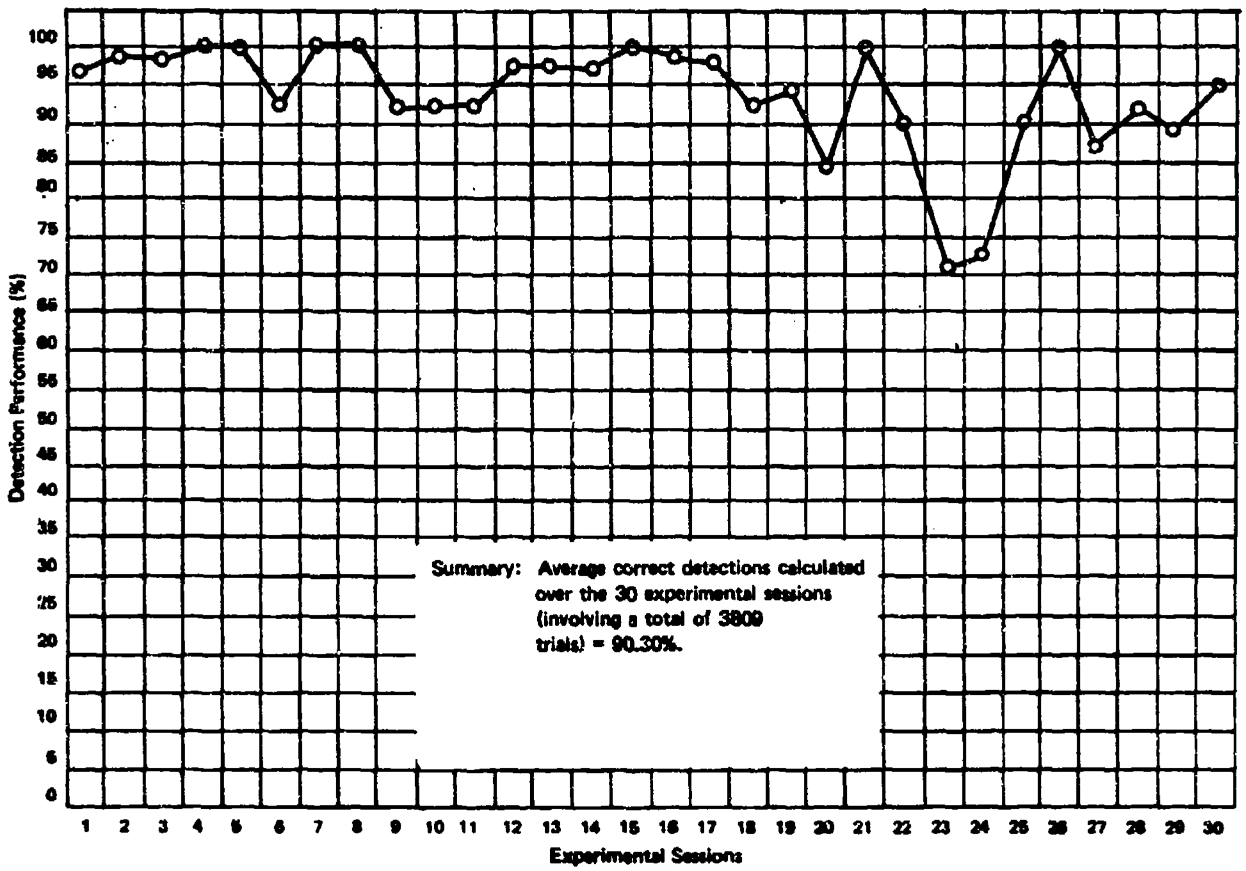


Animal
Skunk
(Pedro)

O——O = % correct detections per experimental session

Target Description Code	C	C	C	C	C	C	C	C	C	C	C	C	B	B	B	B	B	B	B	B	B	B	C	C	C	B	B	B	B	B
Number of Trials per Experimental Session	210	167	104	99	103	157	181	133	174	109	116	164	143	166	95	161	111	101	128	83	91	92	99	101	157	116	166	111	103	174

Target Code: A = C-4   B = Comp B   C = TNT   D = Tetryl   E = PETN   F = RDX   G = M-15   H = M-16   I = M-19

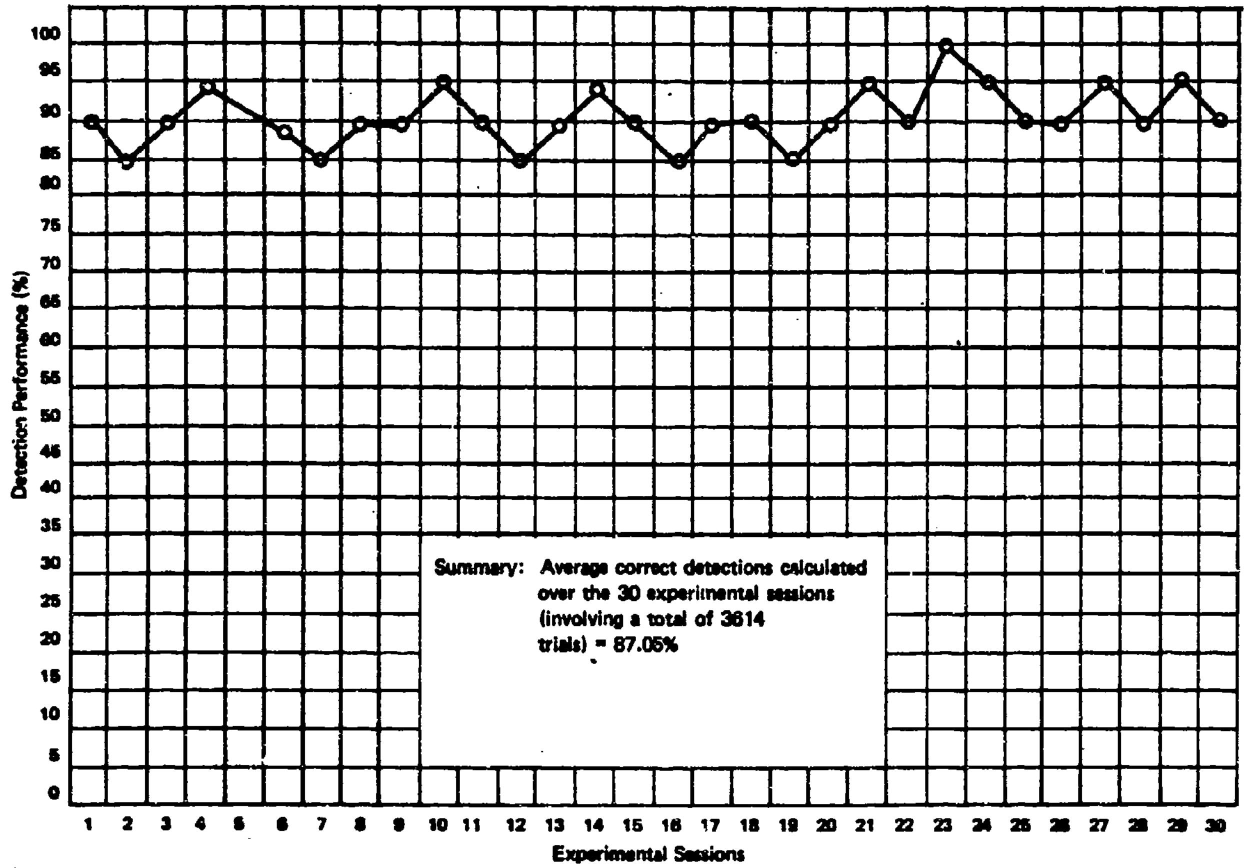


Animal
Domestic Pig
(Greta)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	C	G	G	GHI	G	G	GHI	GHI	GHI	GHI
Number of Trials per Experimental Session	336	300	265	240	120	154	69	214	211	172	47	76	75	93	53	60	75	63	75	39	75	55	80	121	80	120	98	144	168	133

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19



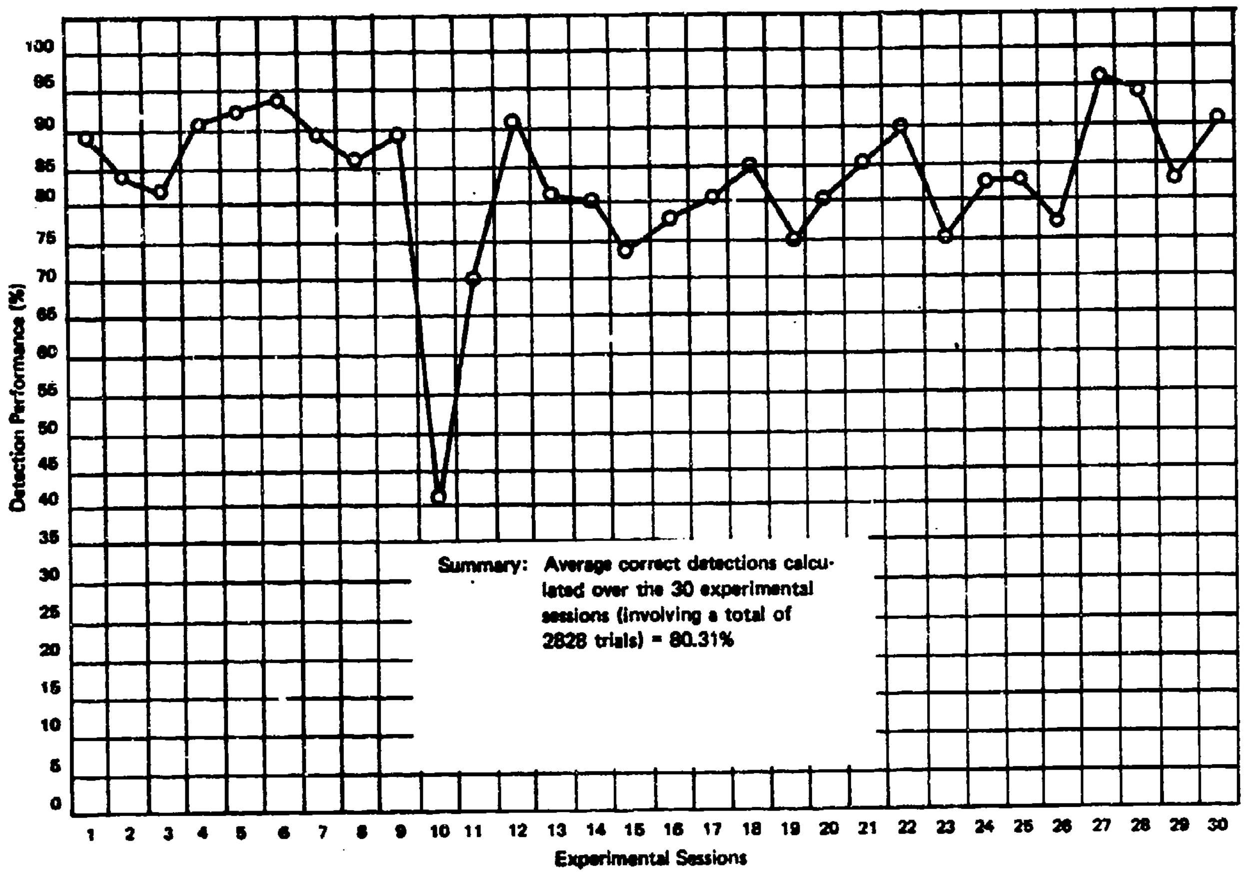
Animal
Ferret
(Slinky)

O—O = % correct detections per experimental session

Experimental Session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target Description Code	C	C	C	C	B	B	B	G	H	I	B	B	C	C	G
Number of Trials per Experimental Session	115	135	248	120	84	150	100	80	75	130	112	65	135	149	120

Experimental Session	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Target Description Code	H	B	C	I	I	G	H	H	I	I	GH/I	GH/I	C	B	I
Number of Trials per Experimental Session	90	110	105	134	116	75	170	60	135	122	66	134	148	160	175

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

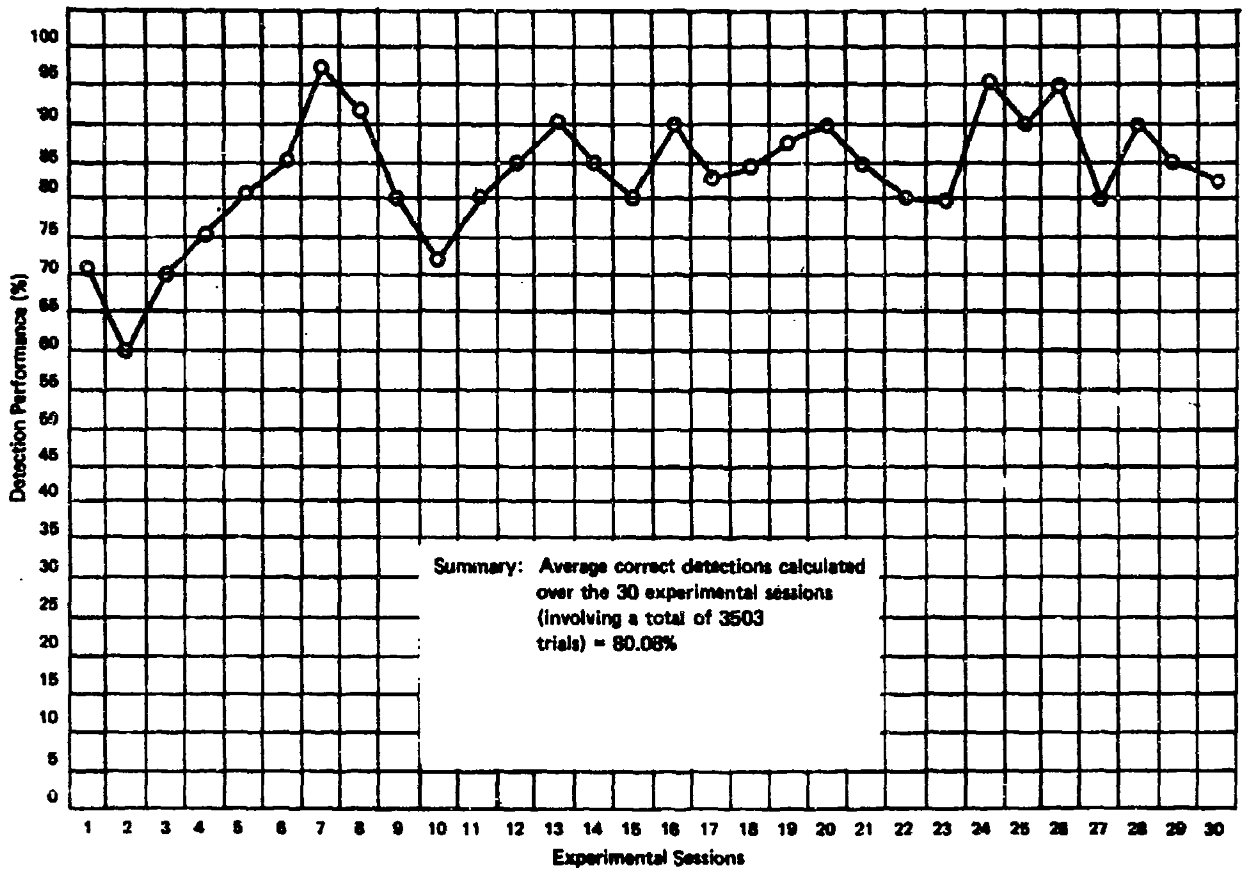


Animal
Domestic Pig
(Rusty)

O——O = % correct detections per experimental session

Target Description Code	C	C	C	C	C	C	C	C	C	B	C	C	B	B	B	GH I	B	B	GH I	GH I	GH I	GH I	GH I	GH I	B	GH I	GH I	B	GH I	B
Number of Trials per Experimental Session	161	297	120	97	90	90	60	60	60	32	76	45	85	75	68	111	85	50	88	97	122	171	122	66	80	88	132	50	101	50

Target Code: A = C-4; B = Comp B; C = TNT; D = Tetryl; E = PETN; F = RDX; G = M-15; H = M-16; I = M-19

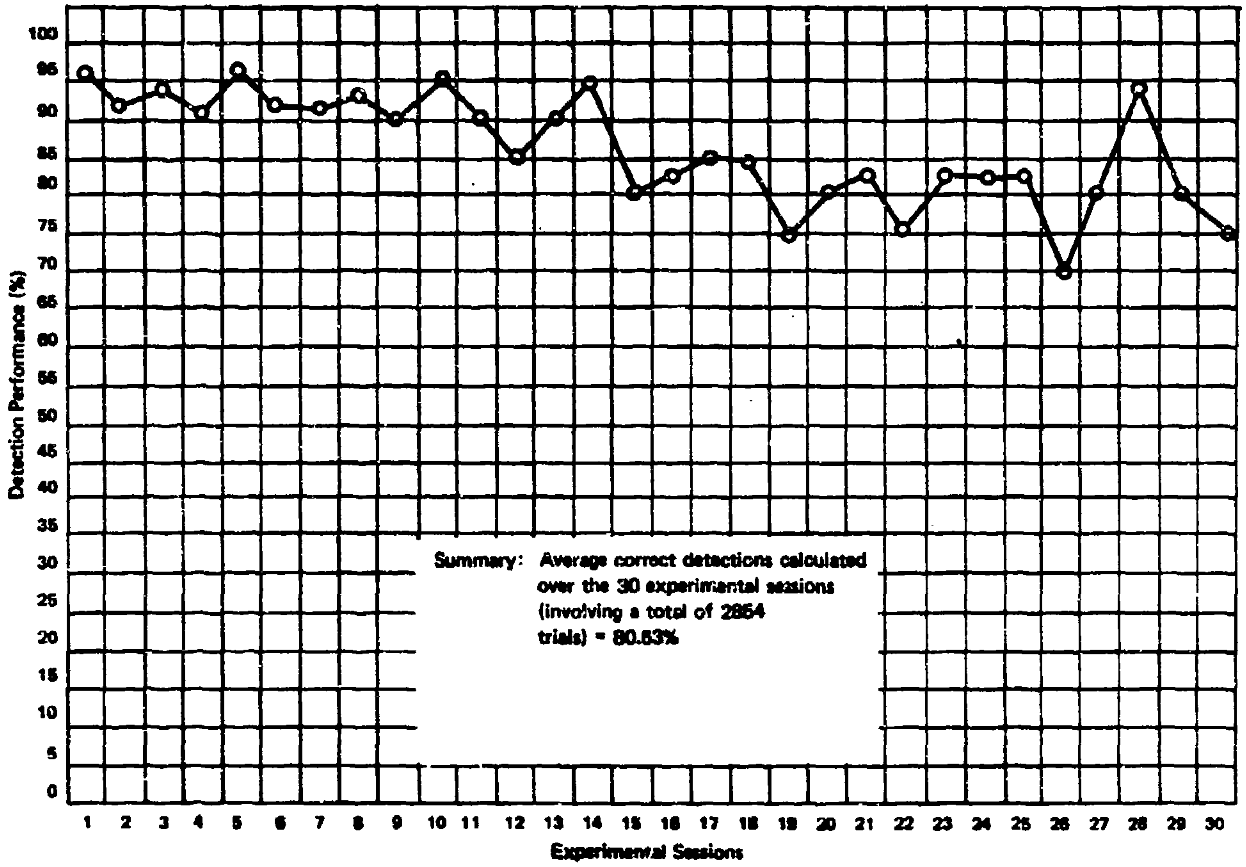


Animal
Miniature Domestic Pig
(Rowdy)

O—O = % correct detections per experimental session

Target Description Code	C	C	C	C	C	B	B	B	B	C	C	C	B	B	GHI	GHI	B	B	C	GHI	GHI	GHI	B	C	C	GHI	GHI	GHI	GHI	GHI
Number of Trials per Experimental Session	131	226	124	107	96	124	117	157	64	45	64	139	117	164	94	87	171	149	197	75	67	141	210	78	92	84	132	57	110	106

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

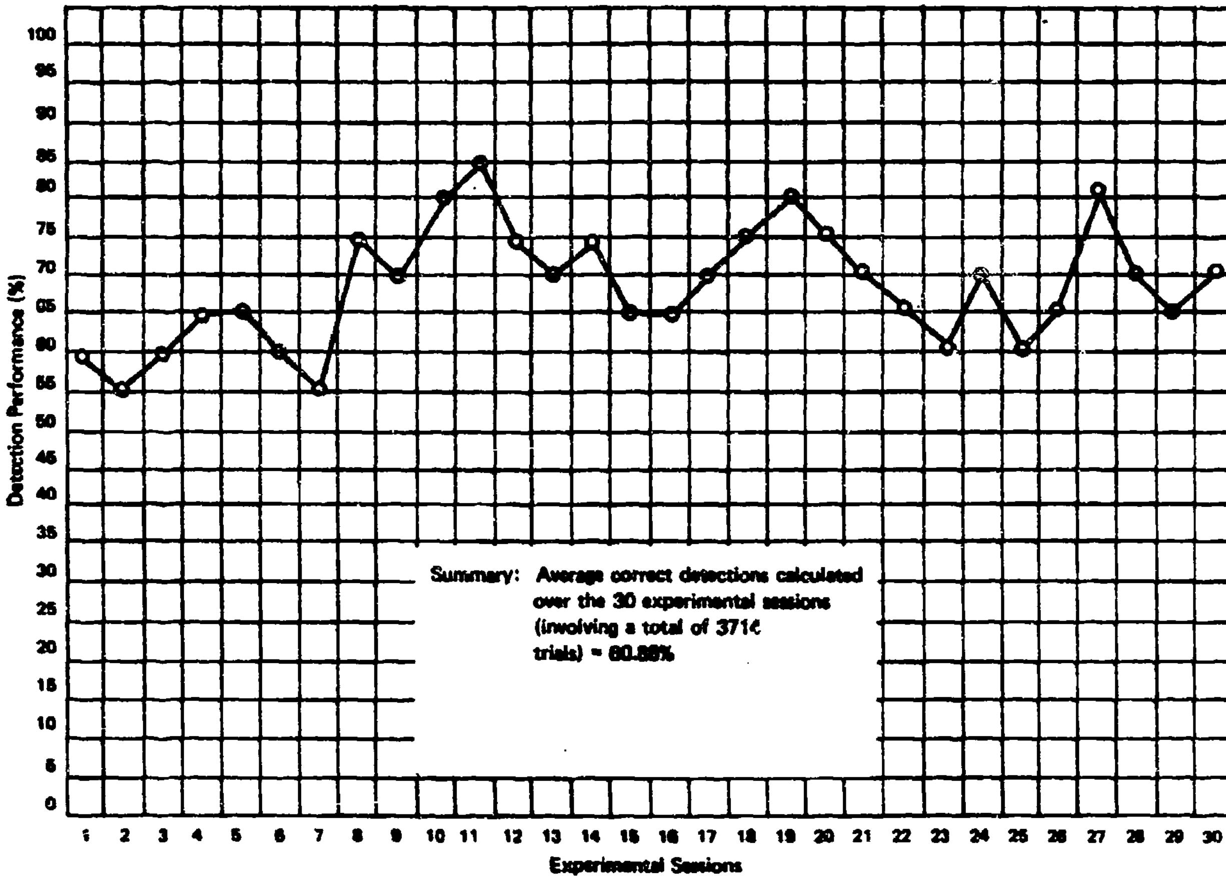


Animal
Silver Fox
(Sherlock)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	GH I	GH I	B	B	B	GH I	B	GH I	GH I	H	GH I
Number of Trials per Experimental Session	170	234	91	67	38	87	75	68	66	60	48	75	45	50	62	60	131	48	56	77	77	222	172	117	115	94	129	90	128	94

Target Code: A = C-4 — B = Comp B — C = TNT — D = Tetryl — E = PETN — F = RDX — G = M-15 — H = M-16 — I = M-19

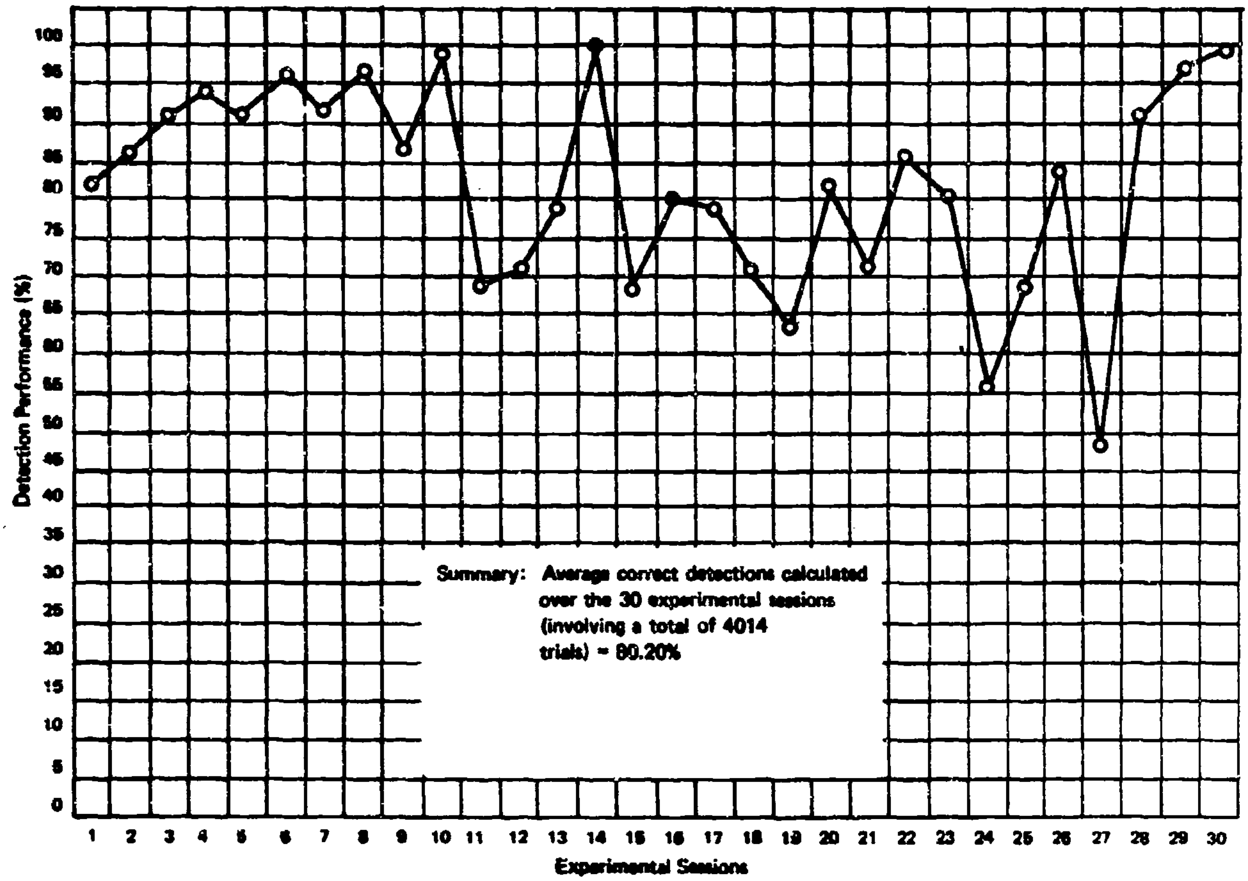


Animal
Raccoon
(Bandit)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	C	C	C	B	B	B	C	C	C	A	A	B	C	C	G	H	I	G	G	GH	GH	GH	GH	C	C	C	C
Number of Trials per Experimental Session	133	150	132	80	126	119	210	150	78	115	170	79	135	180	127	108	168	72	68	107	98	113	124	117	103	141	146	172	113	108

Target Code: A = C-4; B = Comp B; C = TNT; D = Tetryl; E = PETN; F = RDX; G = M-15; H = M-16; I = M-19

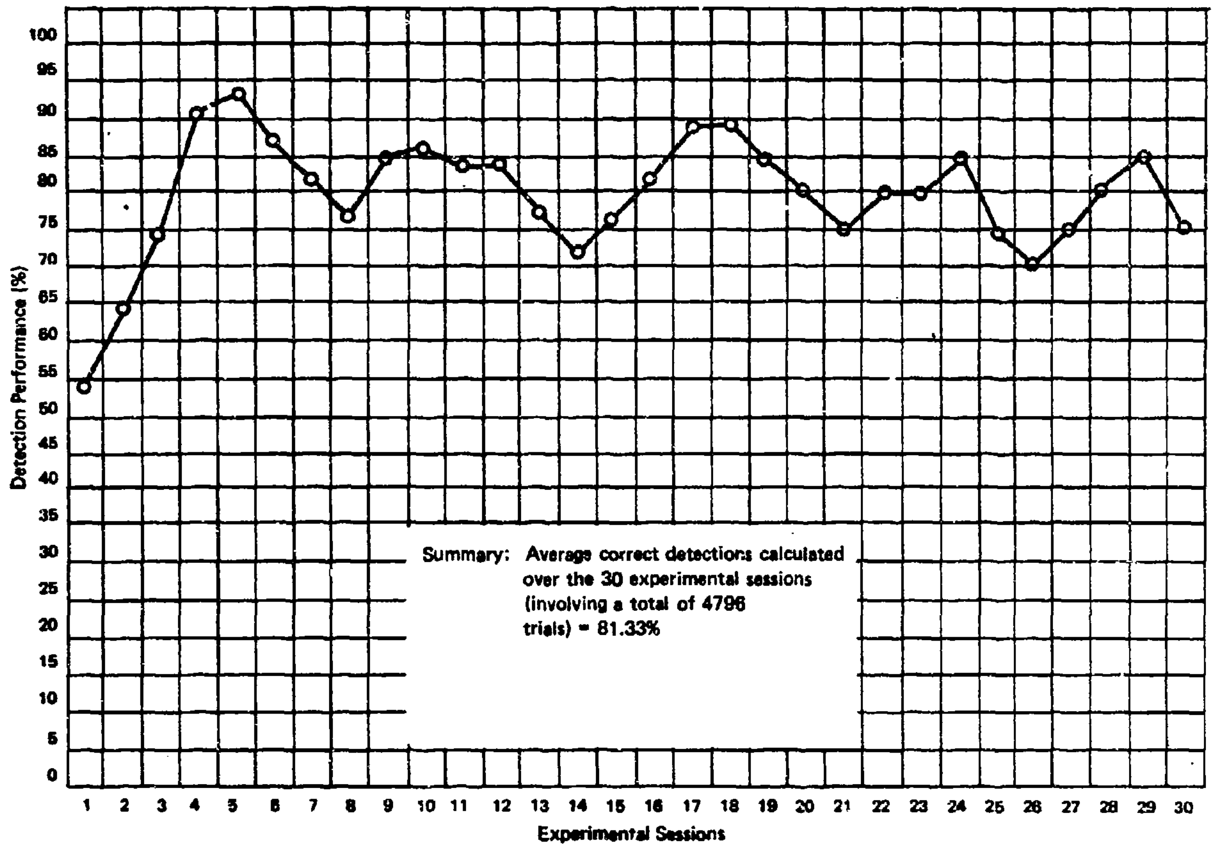


Animal
Javelina
(Rosie)

O—O = % correct detections per experimental session

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Target Description Code	C	C	C	C	C	C	C	C	C	B	B	GHI	B	B	GHI	GHI	GHI	GHI	GHI	GHI	B	GHI	GHI	H	GHI	C	C	H	H	H
Number of Trials per Experimental Session	120	150	288	123	96	160	123	100	90	105	72	132	206	60	186	163	159	135	92	118	106	154	117	65	186	58	156	112	159	165

Target Code: A = C-4; B = Comp B; C = TNT; D = Tetryl; E = PETN; F = RDX; G = M-15; H = M-16; I = M-19

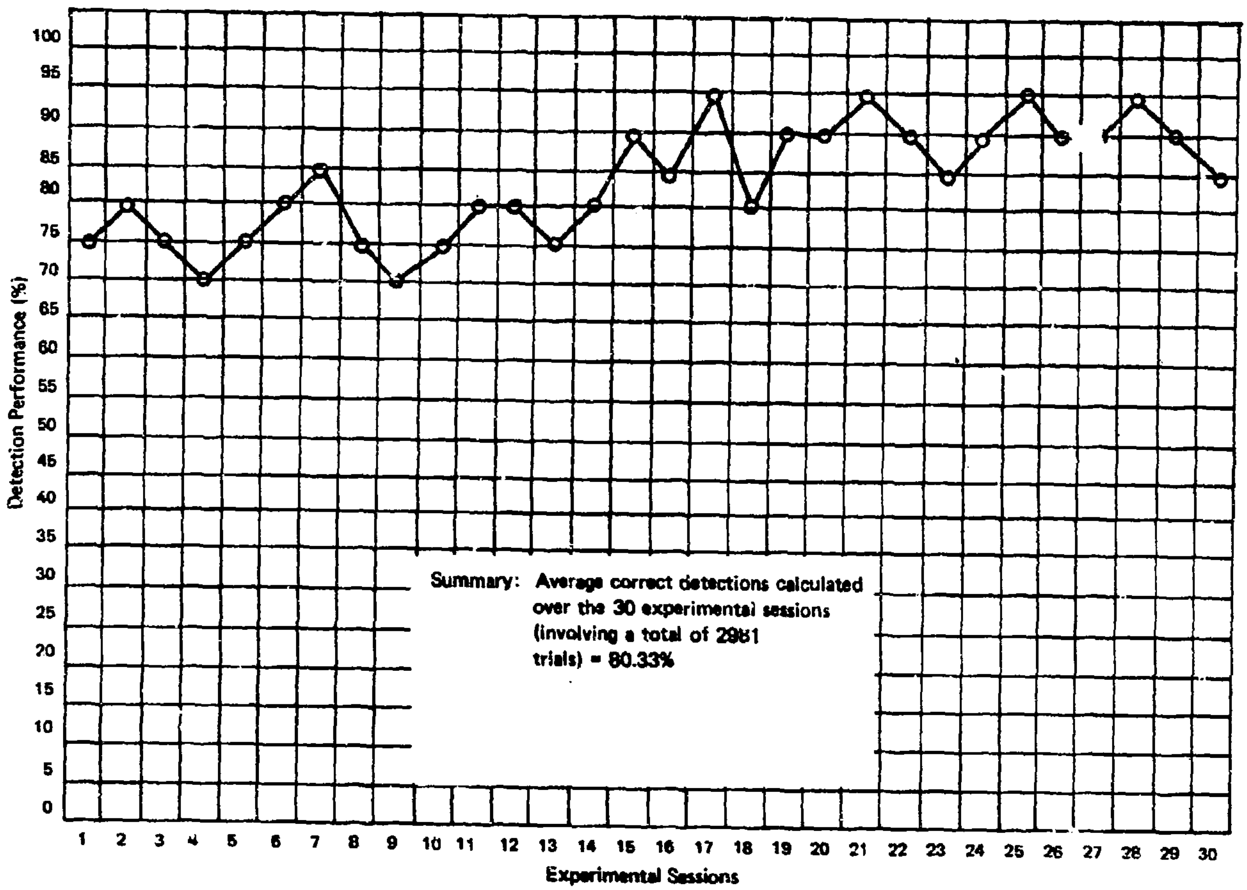


Animal
Coatimundi
(Taisy)

○—○ = % correct detections per experimental session

Target Description Code	A	A	A	B	B	B	B	B	B	B	C	C	C	A	A	B	B	B	B	B	C	C	A	A	A	B	B	B	A	A
Number of Trials per Experimental Session	249	285	159	126	133	173	158	152	150	128	111	98	172	213	98	175	210	133	146	128	191	240	74	135	154	210	159	138	117	182

Target Code: A = C-4
B = Comp B
C = TNT
D = Tetryl
E = PETN
F = RDX
G = M-15
H = M-16
I = M-19



Animal
Coyote
(Wiley)

O—O = % correct detections per experimental session

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target Description Code	C	C	C	C	C	B	B	B	C	C	G	H	I	GHI	GHI
Number of Trials per Experimental Session	150	230	110	107	84	75	66	68	101	39	78	55	76	110	115

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Target Description Code	GHI	B	B	C	C	C	HI	GH	B	B	C	C	GHI	GHI	GHI
Number of Trials per Experimental Session	86	84	99	130	151	78	97	94	120	129	111	125	78	64	93

Target Code:

A = C-4	D = Tetryl	G = M-15
B = Comp B	E = PETN	H = M-16
C = TNT	F = RDX	I = M-19

RESULTS OF OLFACTORY SENSITIVITY EXPERIMENTS CONDUCTED WITH SELECTED CANINE BREEDS AND CROSSES

As indicated earlier, a portion of the olfactory sensitivity study effort was devoted to appraising the olfactory acuity of various breeds of dogs. Prior efforts in this area by the military establishments had focused primarily on two breeds of dogs: the German Shepherd and the Labrador Retriever. Both these breeds had been shown to possess good olfactory acuity. However, it was questionable that they would be able to function effectively in all the extremes of climate and terrain where threats to the National security were presumed to exist (desert, artic, temperate and tropical locations). Information was desired concerning olfactory acuity of other canine breeds which might ultimately be considered as potential candidates for trial as an all-climate explosive detector dog. The relative effectiveness of each of the canine breeds studies—in terms of detecting various explosive targets—is shown in the following table.

Table II. Relative Standing of the Various Canine Breeds Studied in Detecting Explosive Targets

Canine Breed	N	Overall % Correct Detections	Total Number of Trials	Maximum Effective Detection Depth
Australian Dingo	1	88.00%	1080	6
Beagle, mongrel	2	88.75%	1387	6
Border Collie	1	84.73%	508	6
English Sheepdog	2	81.87%	1390	6
Norwegian Elkhound	2	78.52%	2111	6
Mongrel Rabbit Hound	2	91.01%	2398	6
Rhodesian Ridgeback	2	88.68%	2508	6
Welsh Corgi	3	76.99%	1787	6

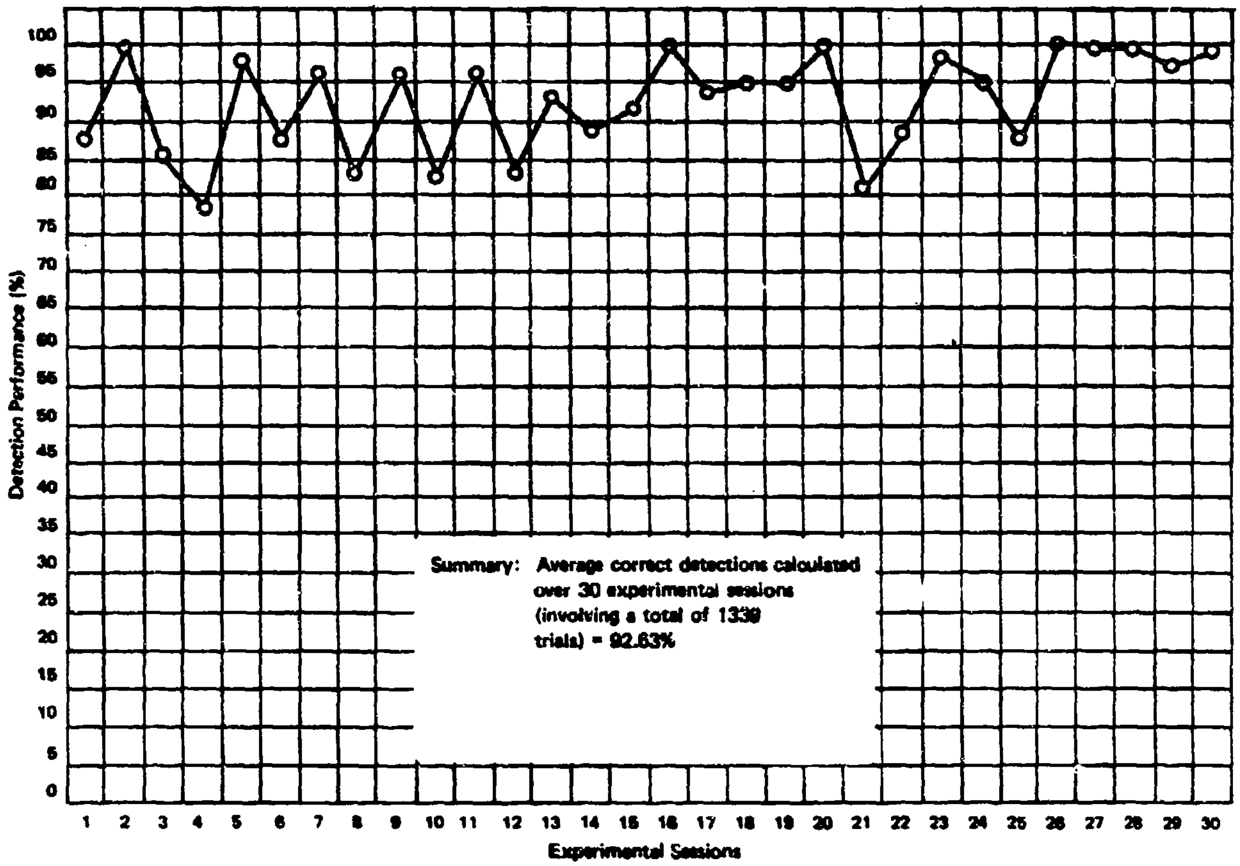
The following pages contain graphic portrayals of the various canine breeds' performance throughout the total study effort. As observed with some of the exotic animal species, several breeds displayed extreme variability in their detection performance which—if it truly were a breed characteristic—would limit the breed's utility for explosives detection purposes. For example, as can be seen by the data contained in the following pages, the Welsh Corgi breed (N = 3) demonstrated extreme variability in detection performance such that the graphic portrayal of their performance has a decided "saw tooth" appearance. Their detection performance—being unpredictable—becomes unreliable for operational purposes. On the other hand, the overall detection performance of the mongrel breeds (Rhodesian Ridgeback/Weimaraner mix; Rabbit Hound mix; and Beagle mix) suggest reasonable consistency in performance at high detection rates. Again, the limited sample sizes used preclude making generalizations across the various breeds concerning olfactory acuity. However, the data does suggest the possible superiority of some breeds over others for explosives detection task. An important task for future research in this area would be to increase the sample size for these (and other) breeds, so that more valid data might be obtained for selecting possibly more effective breeds for assignment to explosives detection tasks.

Though not required contractually, it was considered meaningful to acquire explosives detection performance data on behalf of the German Shepherd and Labrador Retriever breeds for comparative purposes with the other canine breeds specified earlier. This was made possible by extrapolating data derived from a separate research program being carried on concurrently, which specifically focused on the detection performance of the German Shepherd and Labrador Retriever breeds. The results of this research is summarized below.

Table III. Relative Standing of German Shepherd and Labrador Retrievers in Detecting Explosive Targets

Canine Breed	N	Overall % Correct Detections	Total Number of Trials	Maximum Effective Detection Depth
German Shepherd	3	72.22	1948	6
Labrador Retriever	5	72.88	4500	6

Comparison of the data contained in Tables II and III suggests that, in terms of olfactory acuity for explosives detection, other canine breeds (specifically
equal or exceed detection performance of the German Shepherd and Labrador Retriever—breeds traditionally selected for use in explosives detection tasks. A meaningful area for future research would be to evaluate the extent to which these alternative breeds might function effectively under the climatic extremes mentioned earlier.



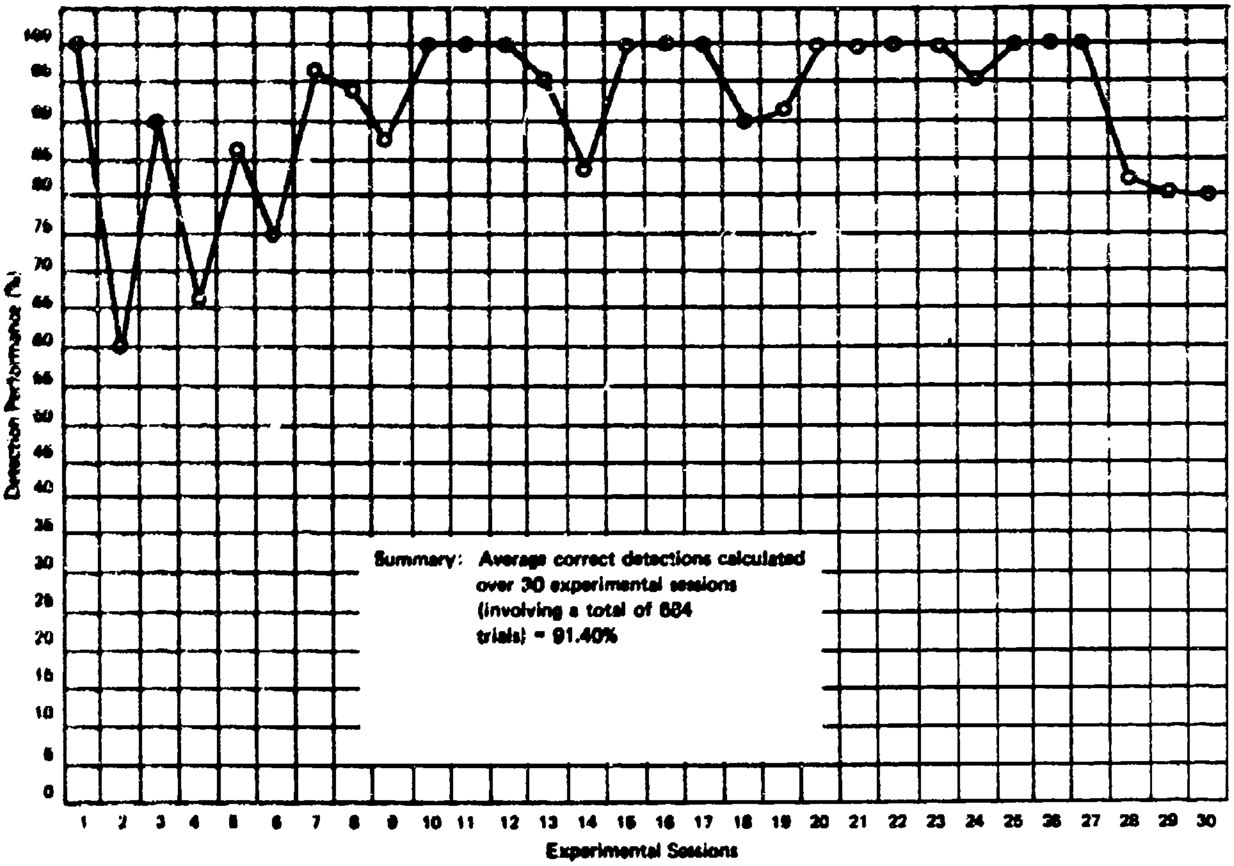
Animal
Mongrel Rabbit Hound
(Jane)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Number of Trials per Experimental Session	60	60	50	51	75	52	50	55	50	55	50	55	59	56	60

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Number of Trials per Experimental Session	6	56	46	40	50	49	25	15	43	18	27	38	35	30	35

Target Code: A = C-4 | D = Tetryl | G = M-15
B = Comp B | E = PETN | H = M-16
C = TNT | F = RDX | I = M-19

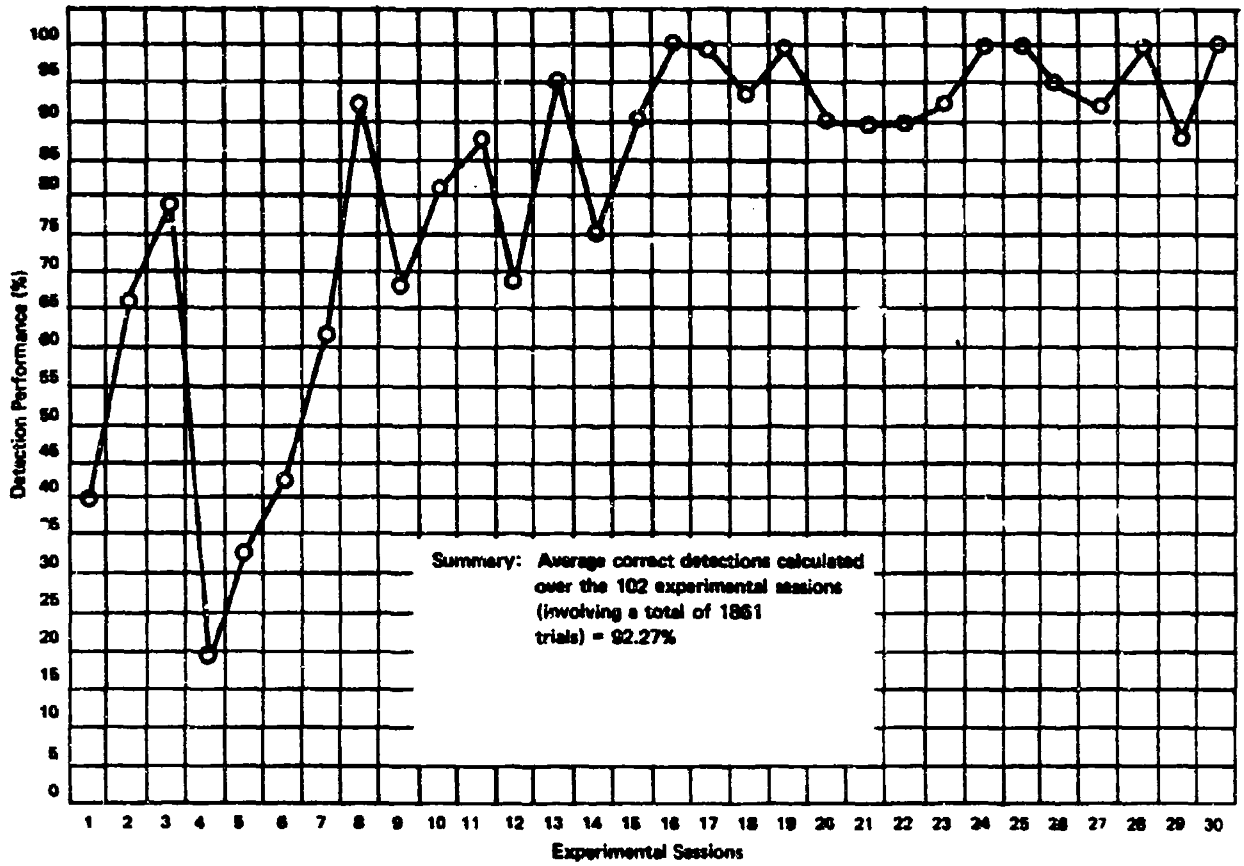


Animal
Mongrel Beagle Mix
(Missy)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	G	G	G
Number of Trials per Experimental Session	15	10	10	12	15	29	29	17	24	20	20	20	20	28	30	30	30	31	25	30	30	25	30	20	30	30	30	23	15	15

Target Code: A = C-4 | B = Comp B | C = TNT | D = Tetryl | E = PETN | F = RDX | G = M-15 | H = M-16 | I = M-19



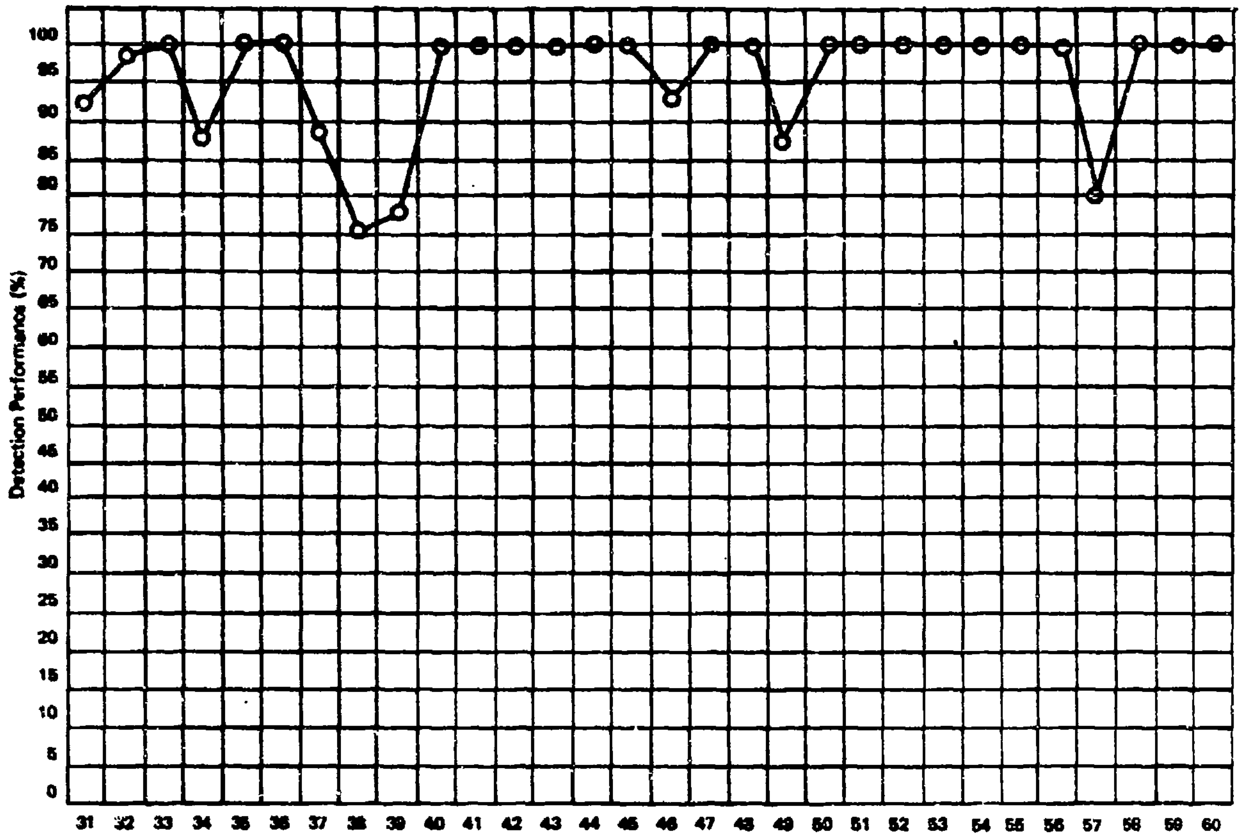
Animal
Rhodesian Ridgeback/
Weimeraner Cross
(Leo)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B
Number of Trials per Experimental Session	10	30	10	10	19	19	18	15	31	33	27	22	20	20	20	20	30	30	30	30	20	30	31	30	30	31	25	30	8	30

Target Code:			
	A = C-4	D = Tetryl	G = M-15
	B = Comp B	E = PETN	H = M-16
	C = TNT	F = RDX	I = M-19

Continuation (Leo)



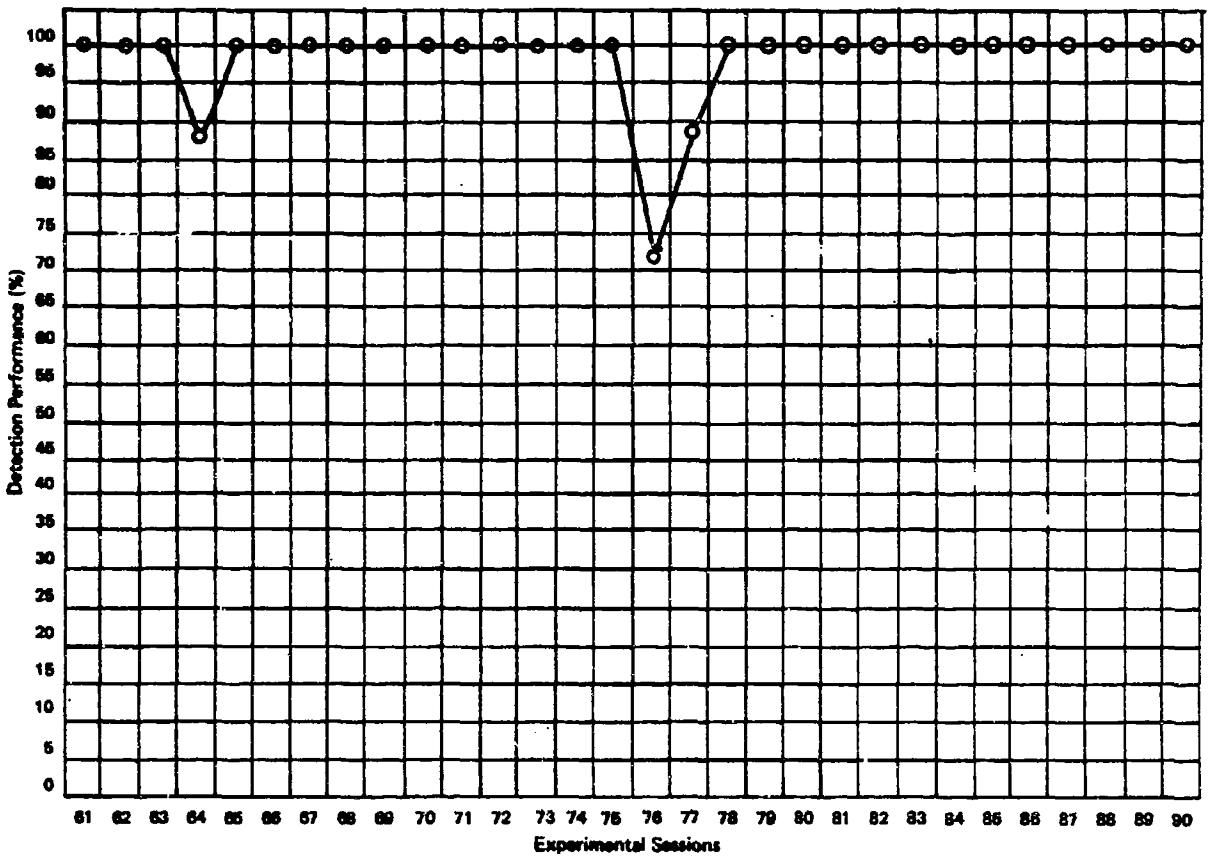
Animal
Rhodesian Ridgeback/
Weimaraner Cross
(Leo)

O—O = % correct detections per experimental session

Target Description Code	B	B	B	G	G	G	H	I	G	G	H	I	G	H	I	G	H	I	G	G	H	I	G	G	H	I	G	G	H	I
Number of Trials per Experimental Session	30	40	15	31	13	24	8	8	14	18	12	12	18	12	14	16	14	18	18	14	12	12	14	18	12	12	15	18	12	14

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

Continuation (Leo)



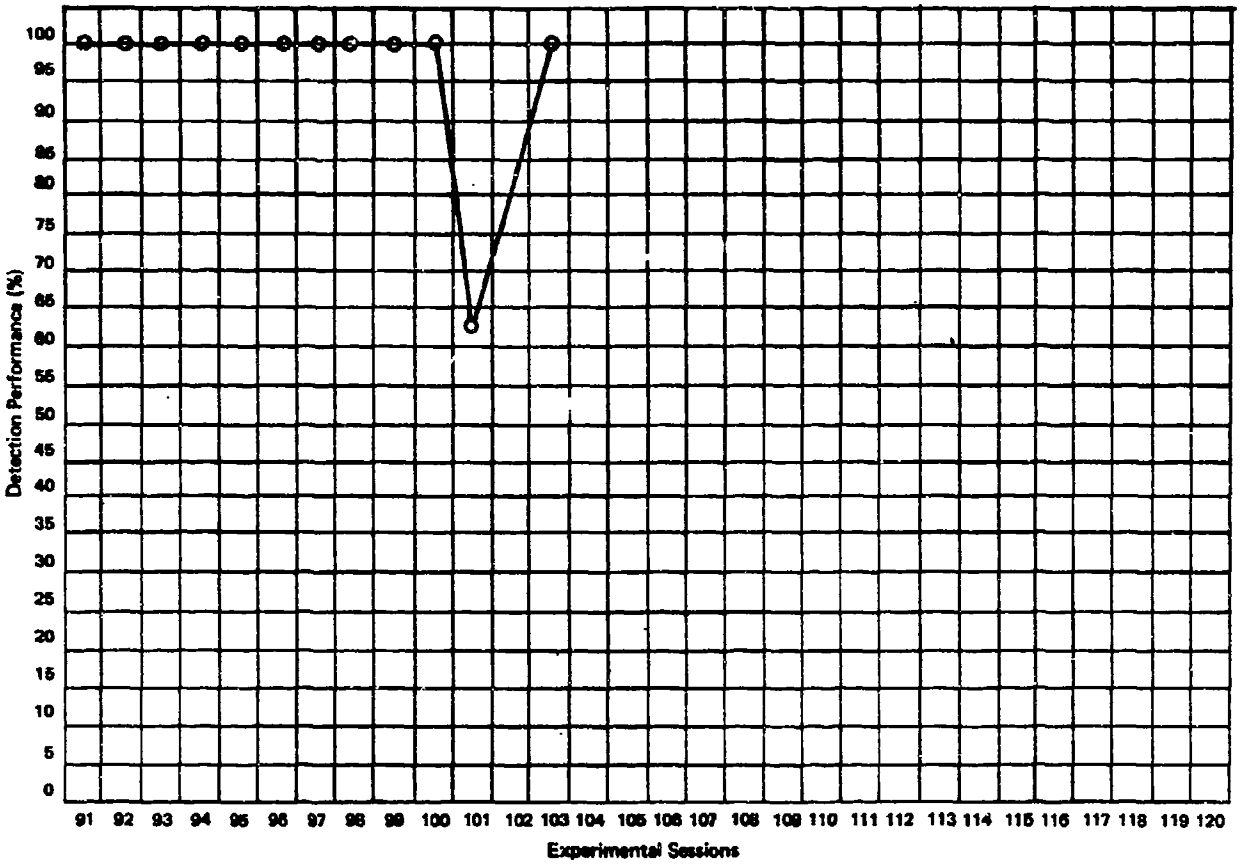
Animal
Rhodesian Ridgeback/
Weimaraner Cross
(Leo)

O—O = % correct detections per experimental session

Target Description Code	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	G	H	I	G	H	I	G	H	I	G	H	I	G	H
Number of Trials per Experimental Session	18	12	14	18	12	14	18	12	14	18	12	14	18	12	14	17	18	12	12	18	12	12	18	12	12	18	12	12	18	12

Target Code: A = C-4 B = Comp B C = TNT D = Tetryl E = PETN F = RDX G = M-15 H = M-16 I = M-19

Continuation (Leo)

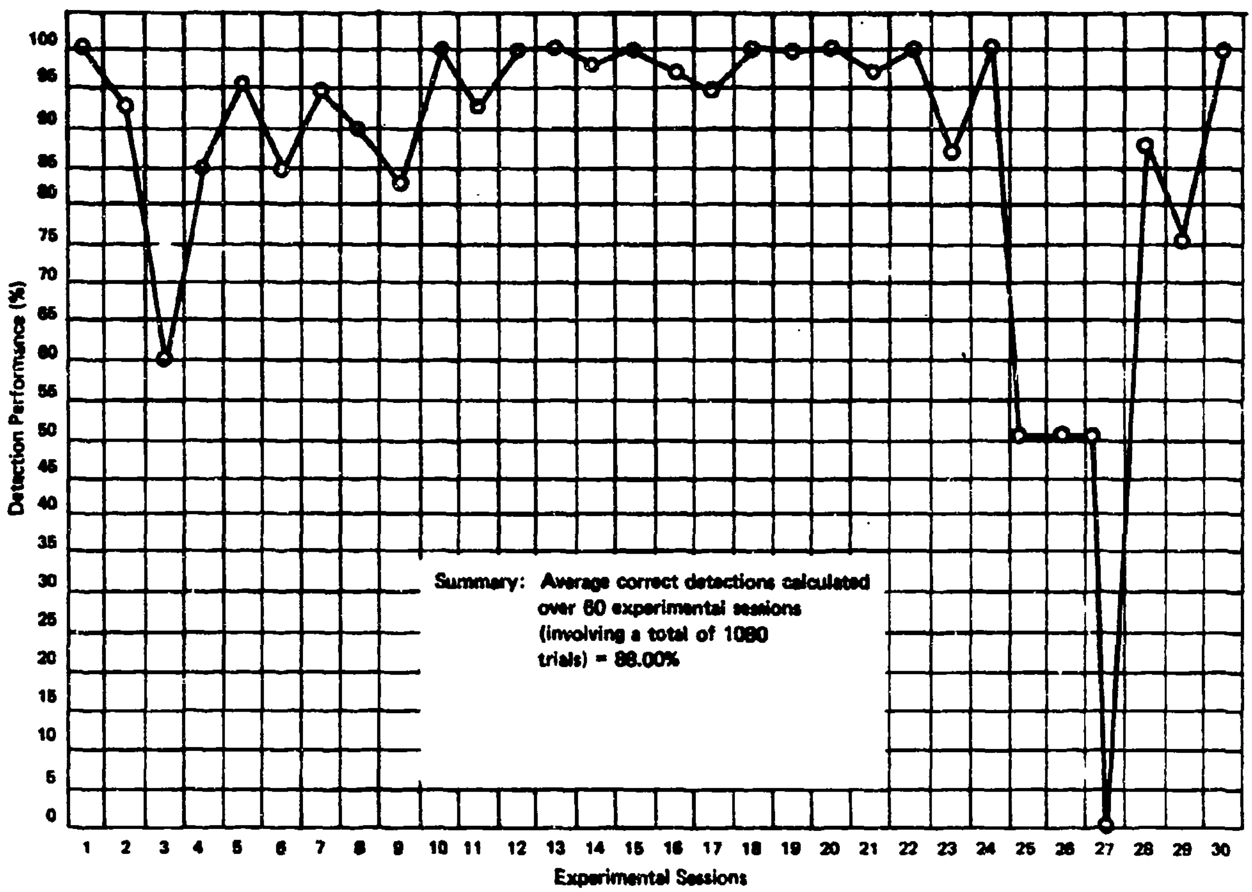


Animal
Rhodesian Ridgeback/
Weimaraner Cross
(Leo)

O——O = % correct detections per experimental session

Target Description Code	I	G	H	I	G	H	I	G	H	I	G	H	I
Number of Trials per Experimental Session	12	18	13	14	18	13	14	18	13	14	18	12	12

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

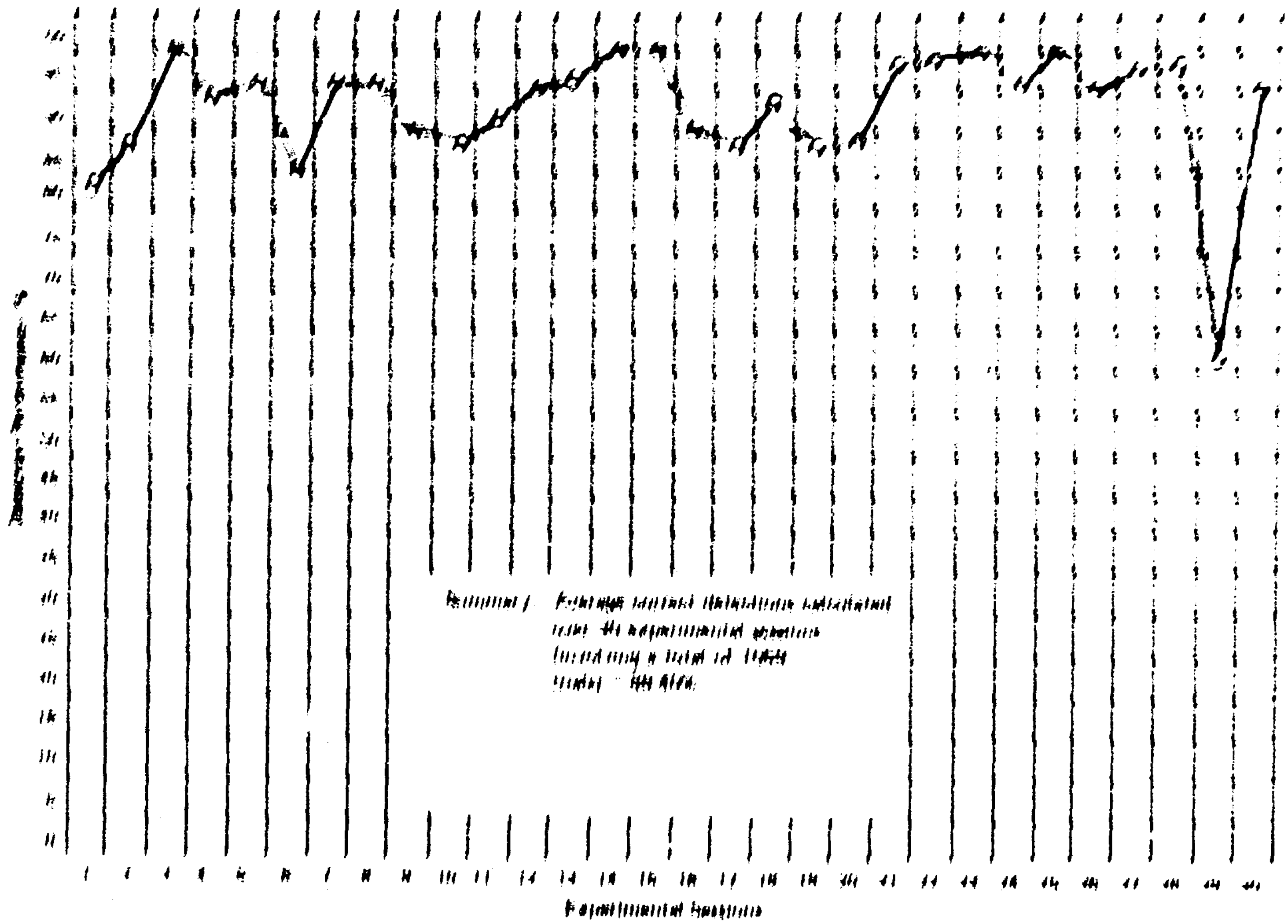


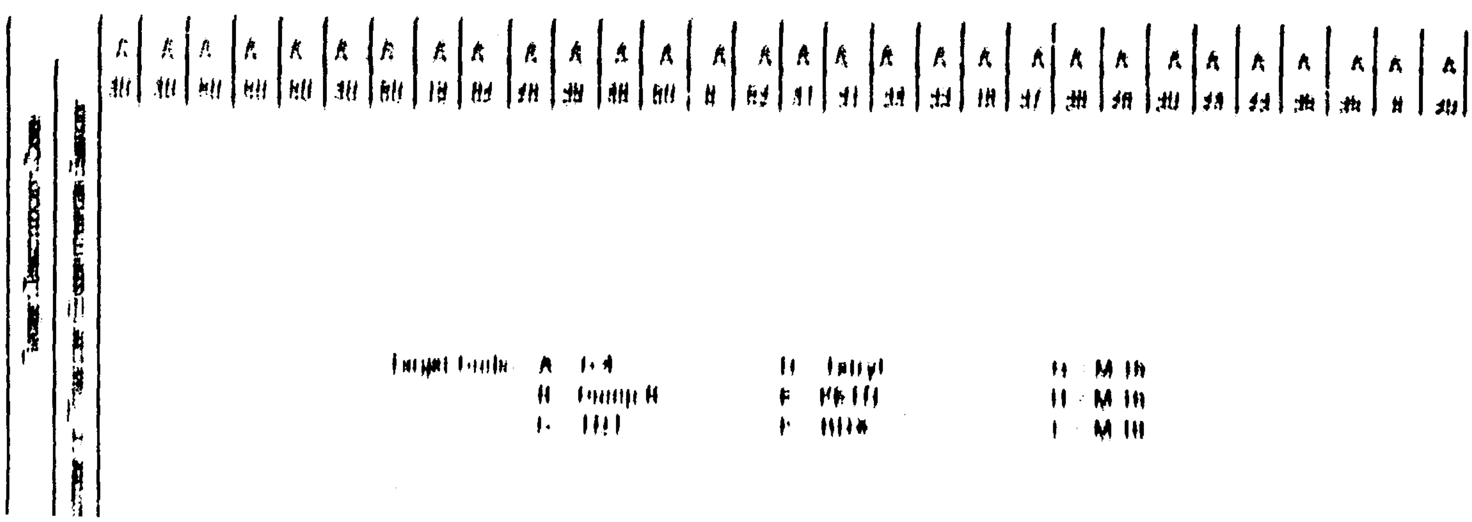
Animal
Australian Dingo
(Bingo)

○—○ = % correct detections per experimental session

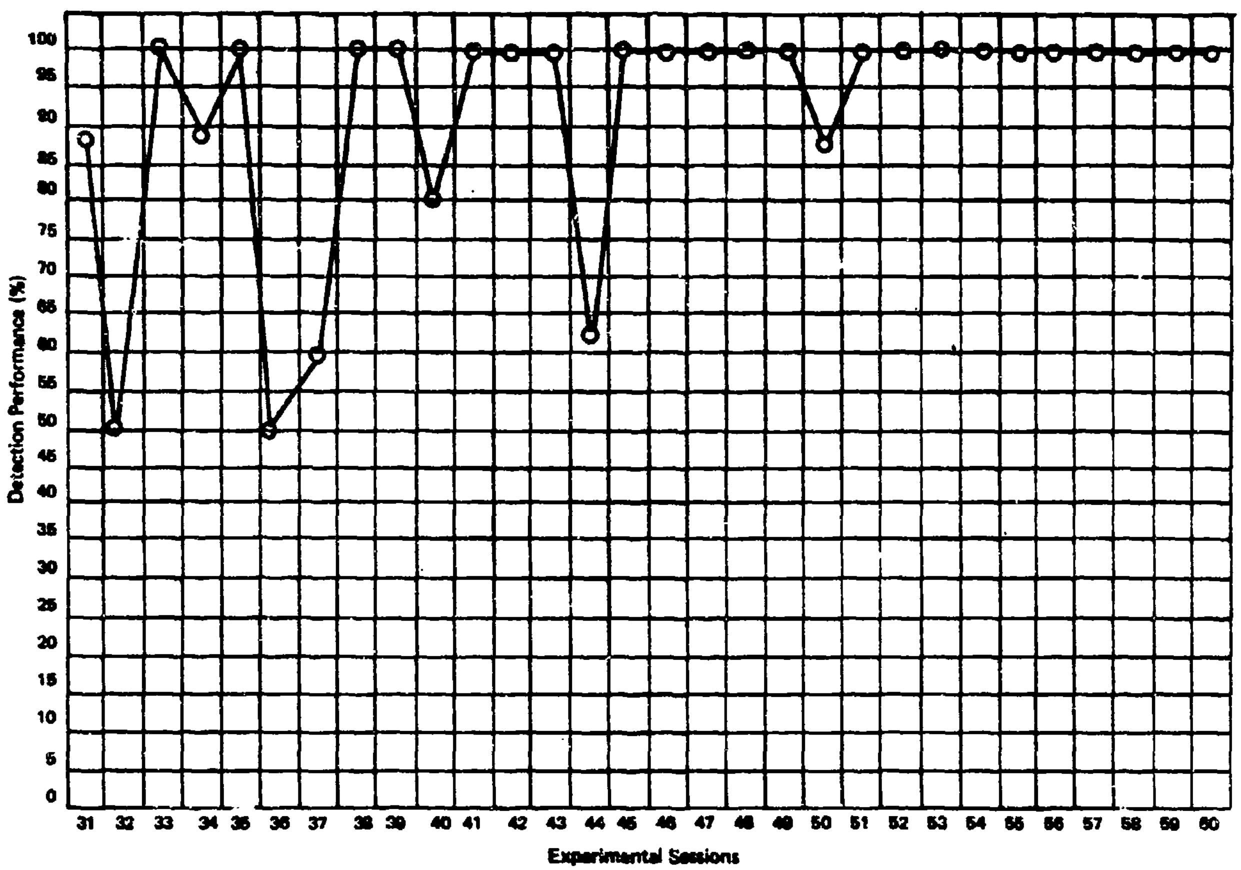
Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	D	B	G	H	I	G	H	I
Number of Trials per Experimental Session	30	35	15	20	20	20	20	20	24	25	25	20	20	30	30	25	20	30	19	33	30	25	15	18	19	12	12	16	14	14

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19





Continuation (Bingo)

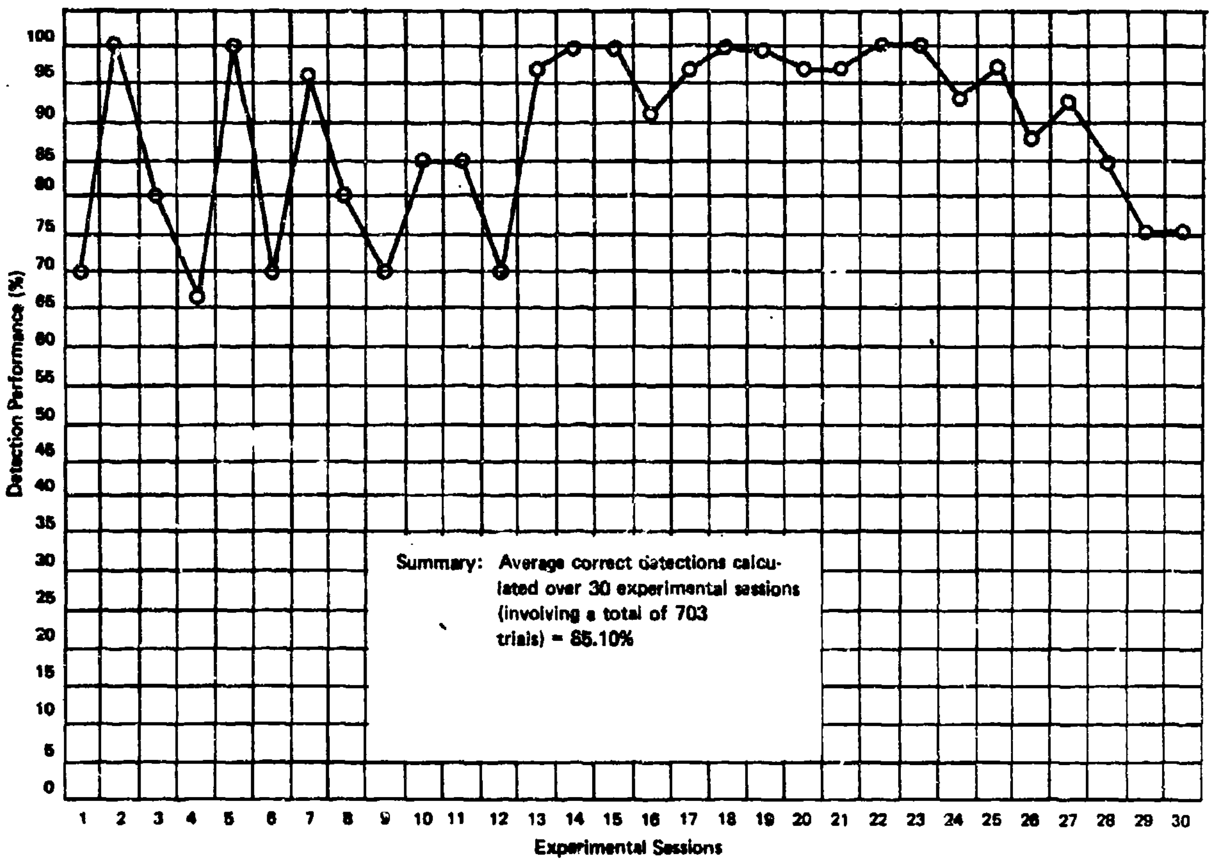


Animal
Australian Dingo
(Bingo)

O—O = % correct detections per experimental session

Target Description Code	G	H	I	G	H	I	G	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H
Number of Trials per Experimental Session	18	12	14	18	12	12	15	18	12	14	18	12	12	18	12	14	18	12	14	18	12	14	18	12	14	18	12	12	18	12

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

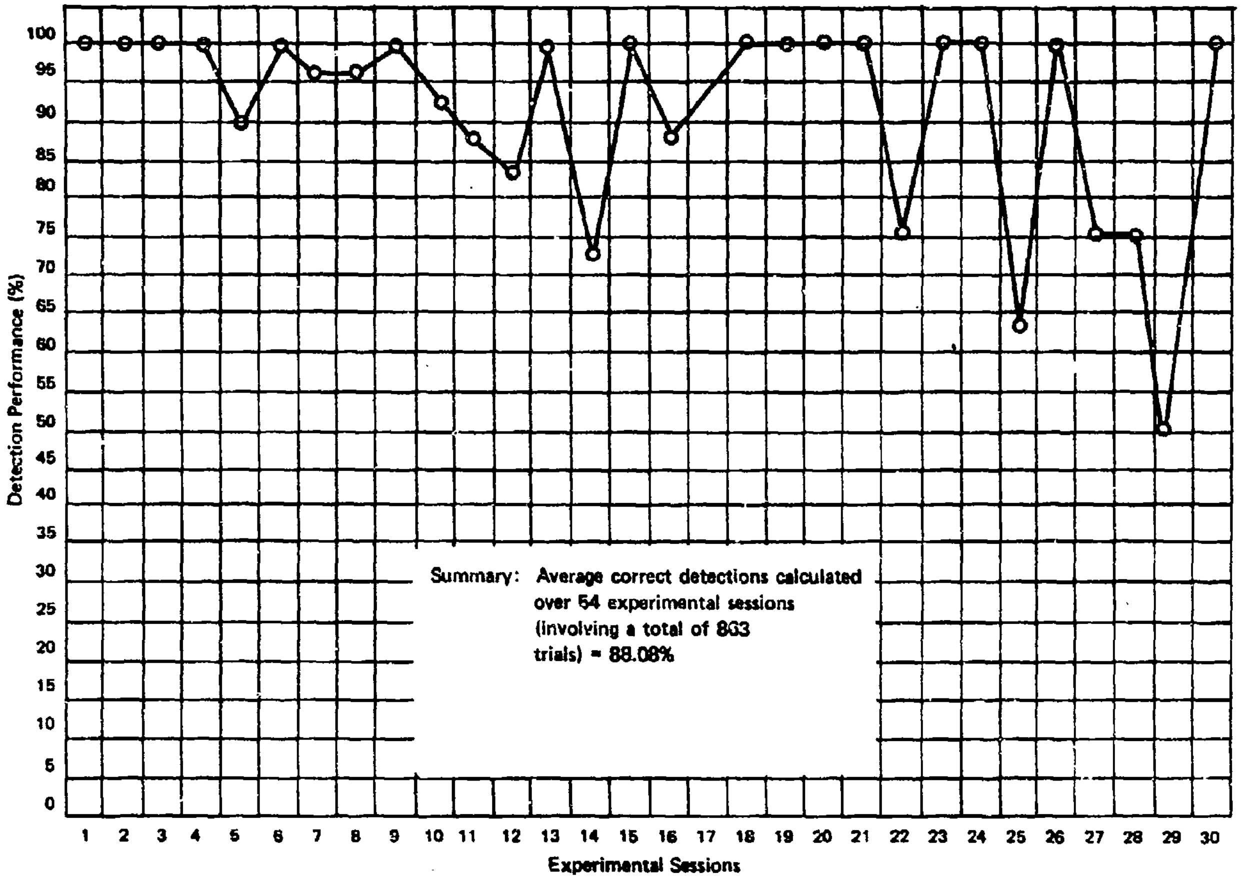


Animal
Mongrel Beagle Mix
(Sissy)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	G	G	G	G	H
Number of Trials per Experimental Session	10	15	11	12	15	31	31	30	21	20	20	20	30	30	30	24	32	30	30	30	30	15	30	31	30	25	15	15	16	14

Target Code: A = C-4 | D = Tetryl | G = M-15
B = Comp B | E = PETN | H = M-16
C = TNT | F = RDX | I = M-19



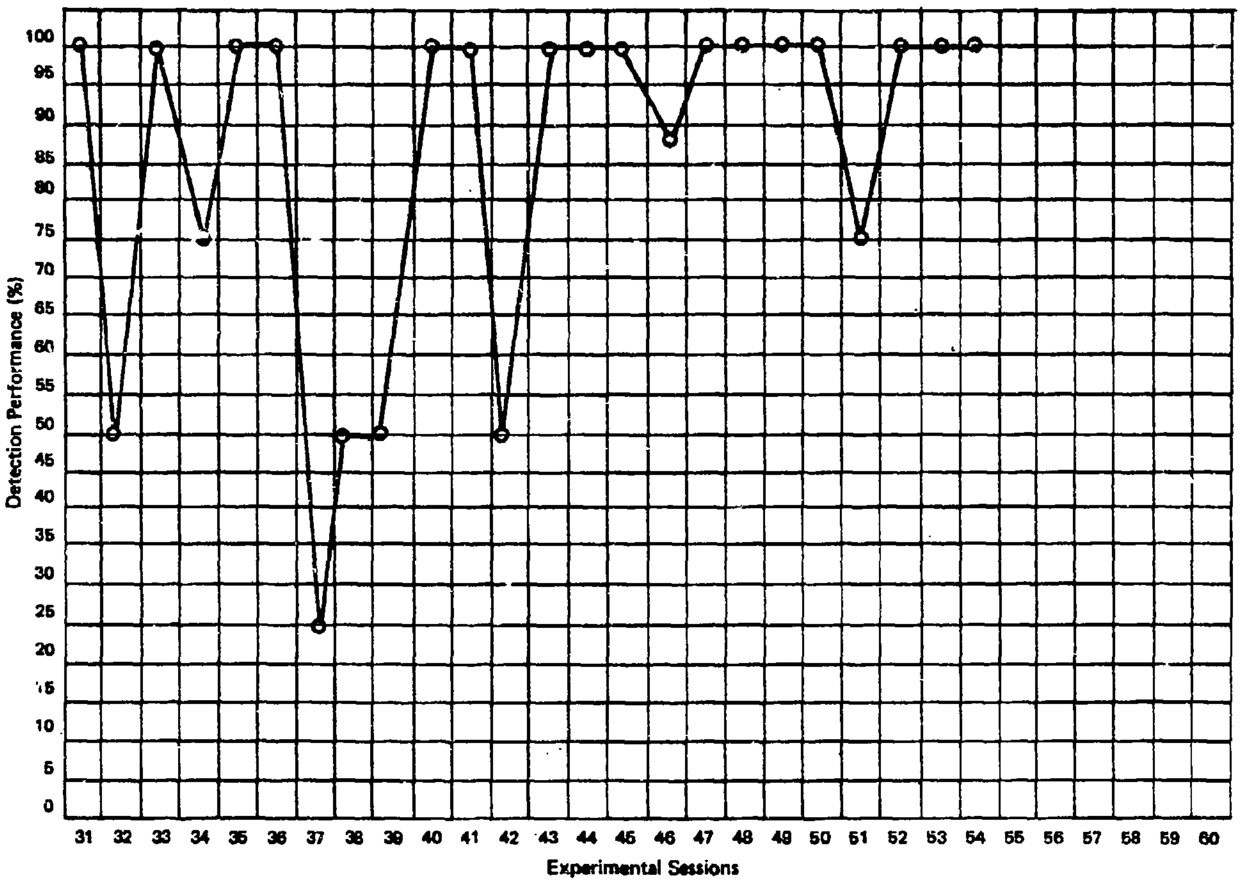
Animal
English Sheep dog
(Liz)

O——O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	B	B	B	B	G	G	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I
Number of Trials per Experimental Session	20	20	15	20	20	20	30	30	30	16	25	25	15	15	14	18	12	12	18	12	12	12	13	12	18	12	14	18	12	14

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

Continuation (Liz)

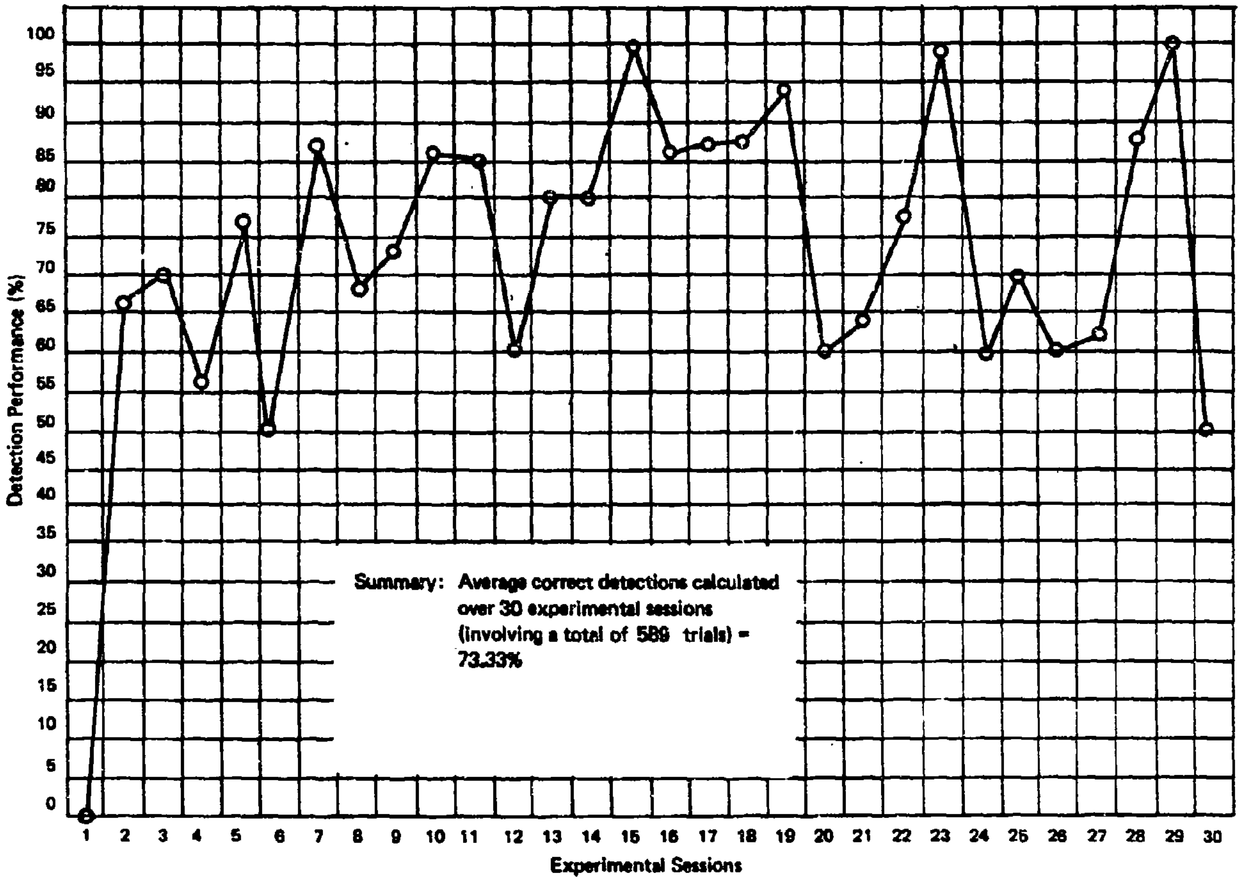


Animal
English Sheep dog
(Liz)

O—O = % correct detections per experimental session

Target Description Code	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I
Number of Trials per Experimental Session	18	12	14	18	12	14	18	12	14	18	12	12	14	11	12	18	12	12	18	13	14	18	11	12

Target Code: A = C-4 B = Comp B C = TNT D = Tetryl E = PETN F = RDX G = M-15 H = M-16 I = M-19

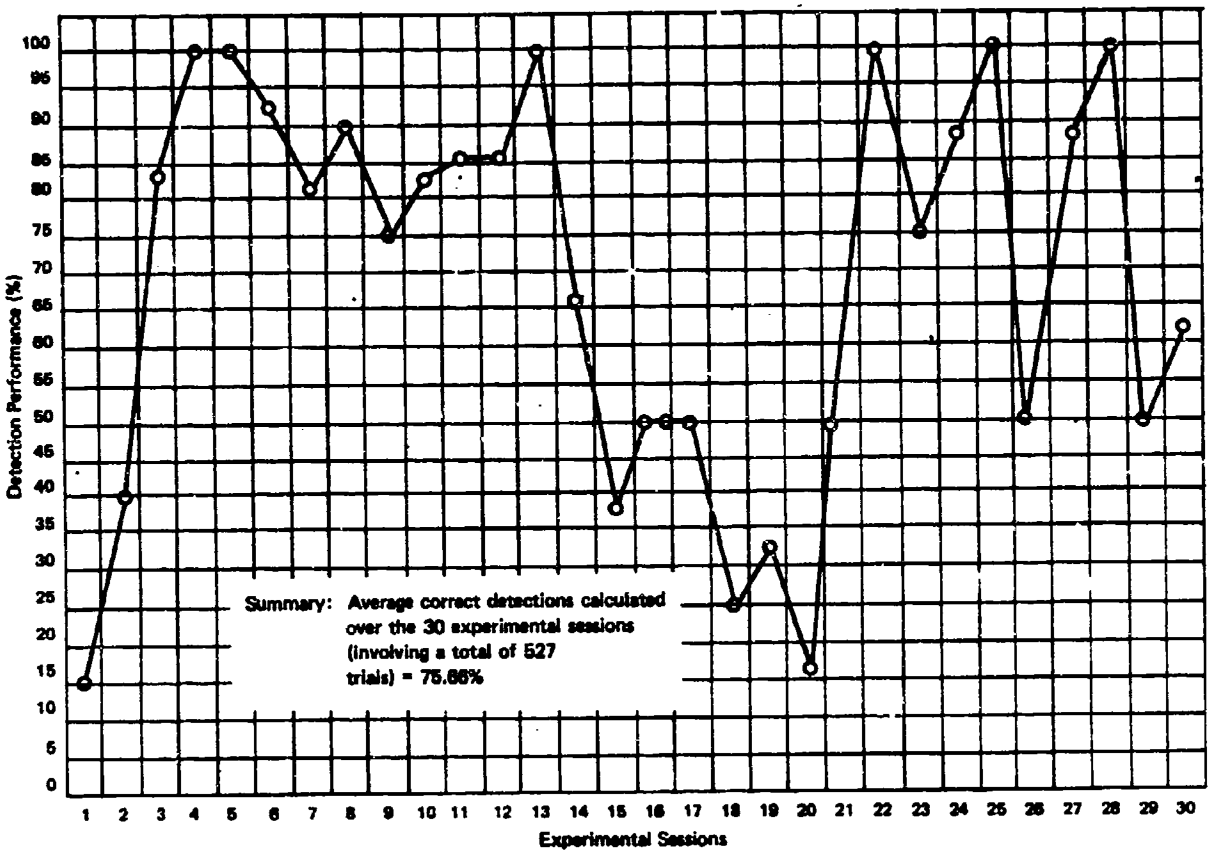


Animal
Norwegian
Elkhound
(Leif)

O——O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	G	G	G
Number of Trials per Experimental Session	5	15	10	16	9	16	16	28	30	15	20	15	20	20	20	30	30	31	17	10	17	19	13	30	30	30	30	16	15	16

Target Code: A = C-4 D = Tetryl G = M-15
B = Comp B E = PETN H = M-16
C = TNT F = RDX I = M-19

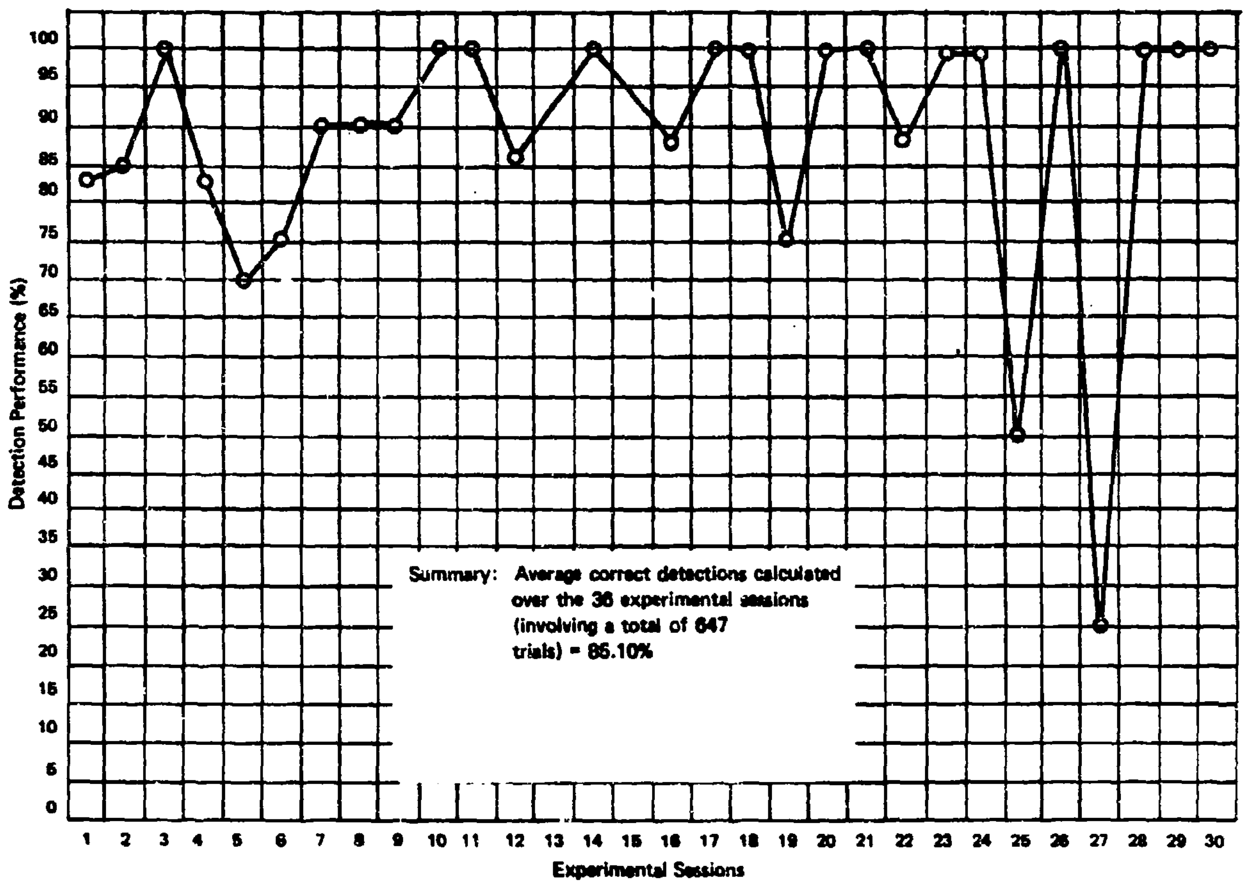


Animal
English Sheep dog
(Richard)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	B	B	B	G	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G
Number of Trials per Experimental Session	20	20	30	14	15	16	16	30	20	30	30	15	25	15	18	12	12	12	13	16	18	12	14	18	12	14	18	12	12	18

Target Code: A = C-4   D = Tetryl   G = M-15
B = Comp B   E = PETN   H = M-16
C = TNT   F = RDX   I = M-19



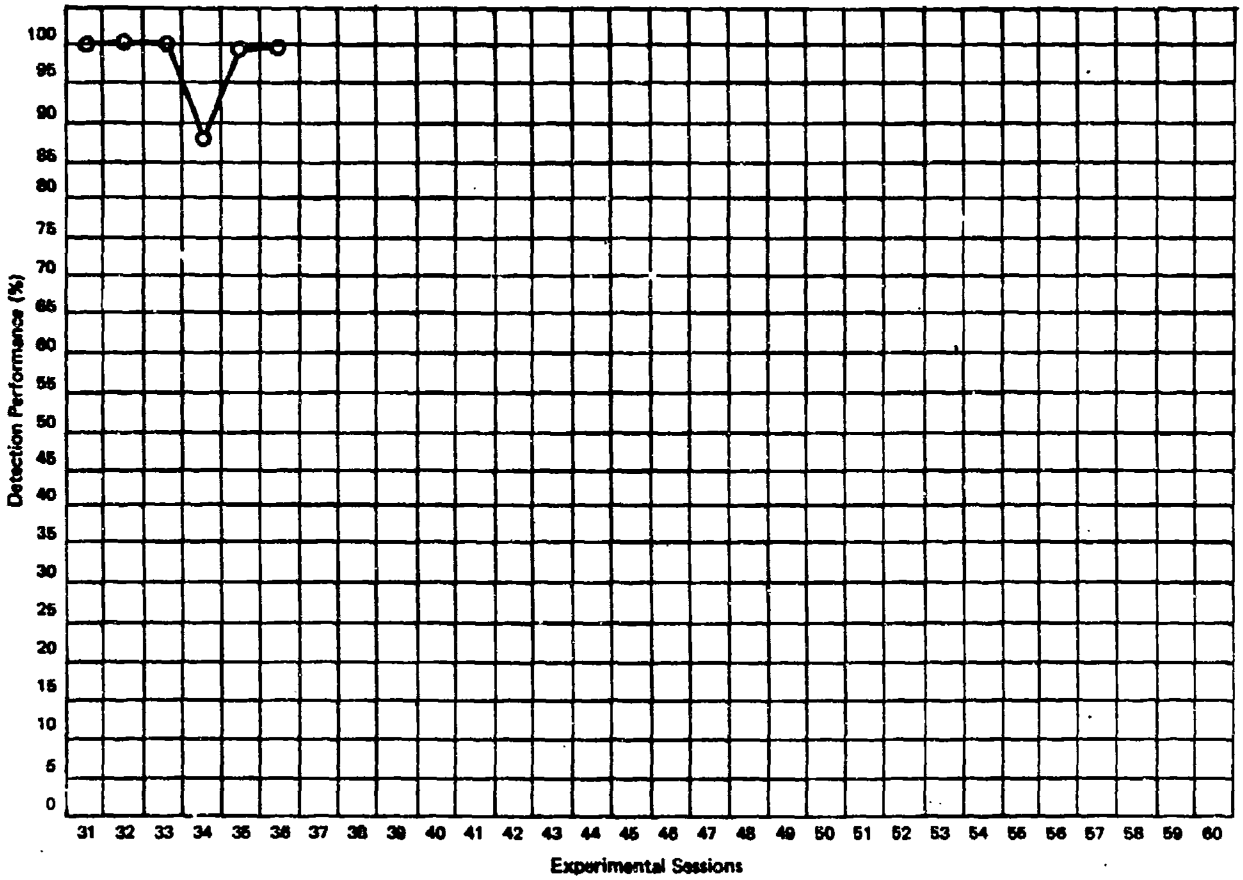
Animal
Rhodesian Ridgeback/
Weimaraner Cross
(Leona)

O——O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	B	B	B	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I
Number of Trials per Experimental Session	18	20	30	30	30	12	20	20	30	30	30	30	18	12	14	18	12	12	18	13	14	18	12	14	18	12	14	18	12	14

Target Code: A = C-4 | D = Tetryl | G = M-15
B = Comp B | E = PETN | H = M-16
C = TNT | F = RDX | I = M-19

Continuation (Leona)

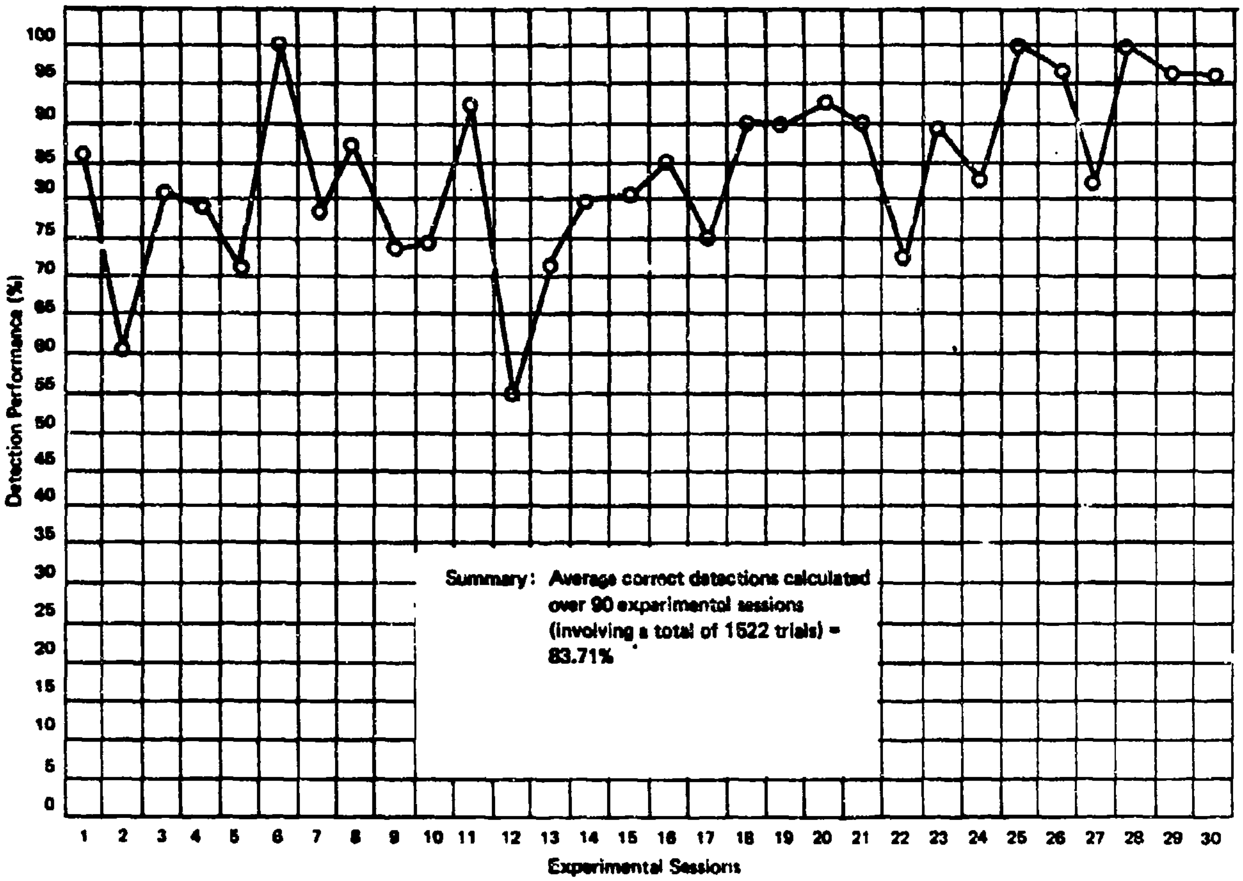


Animal
Rhodesian Ridgeback/
Weimaraner Cross
(Leona)

O—O = % correct detections per experimental session

Target Description Code	G	H	I	G	H	I																								
Number of Trials per Experimental Session	18	12	12	18	12	12																								

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19



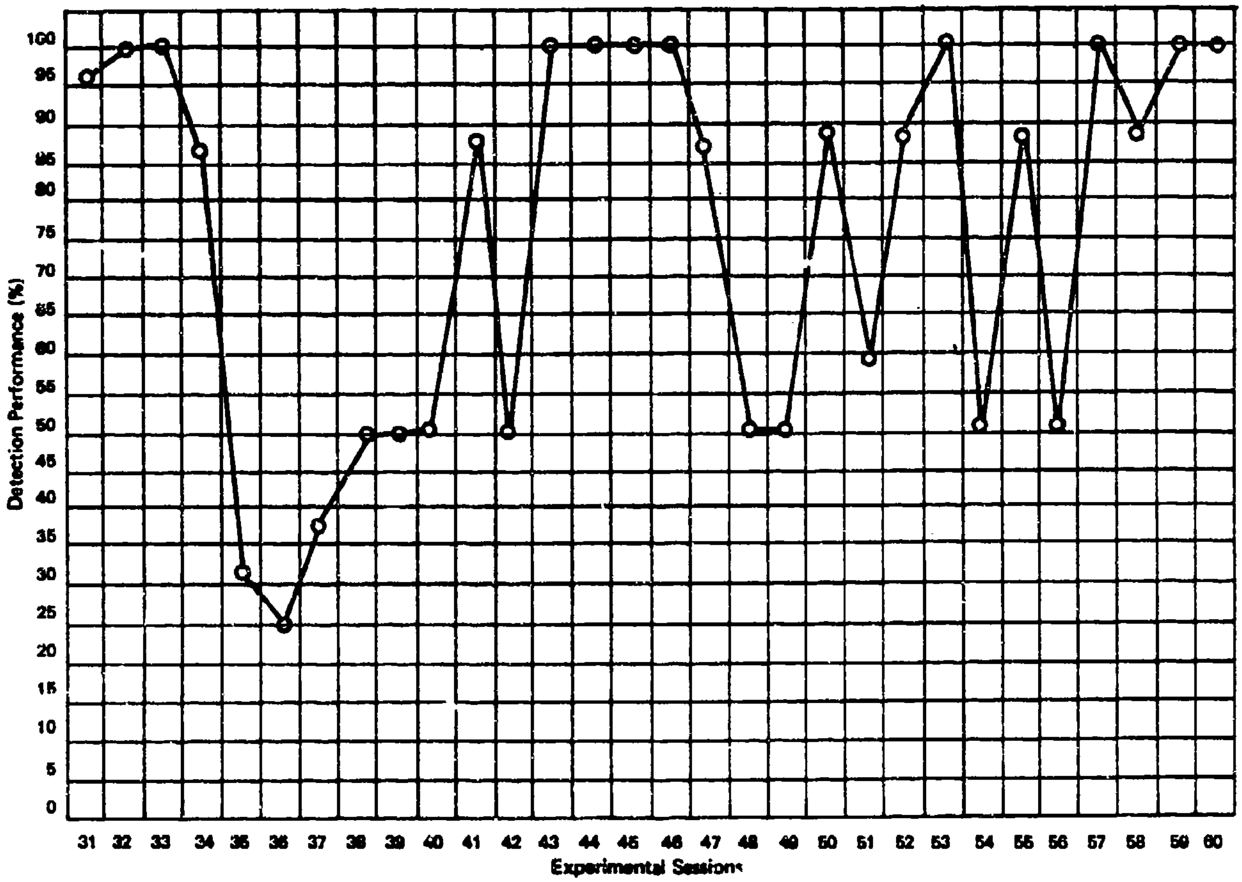
Animal
Norwegian
Elkhound
(Erica)

O——O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B
Number of Trials per Experimental Session	15	20	15	15	21	11	14	15	31	25	30	20	14	20	20	20	20	20	20	30	20	15	20	30	30	31	31	10	25	30

Target Code: A = C-4
B = Comp B
C = TNT
D = Tetryl
E = PETN
F = RDX
G = M-15
H = M-16
I = M-19

Continuation (Erica)



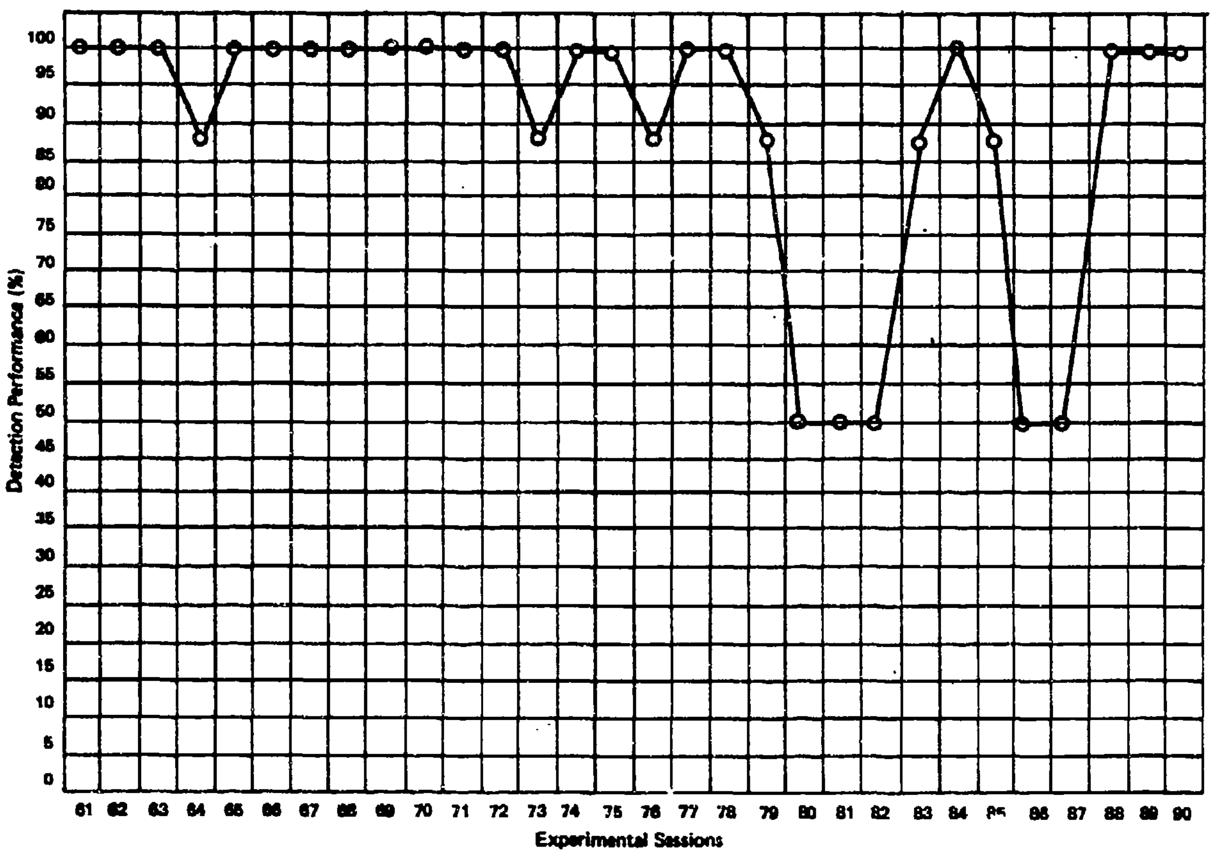
Animal
Norwegian
Elkhound
(Erica)

○—○ = % correct detections per experimental session

Target Description Code	B	B	B	G	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	G	G	H	I	G	H	I	G	H	I
Number of Trials per Experimental Session	30	25	15	15	16	14	18	18	12	12	18	12	14	18	12	12	18	12	12	19	15	18	12	14	18	12	14	18	12	14

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19

Continuation (Erica)

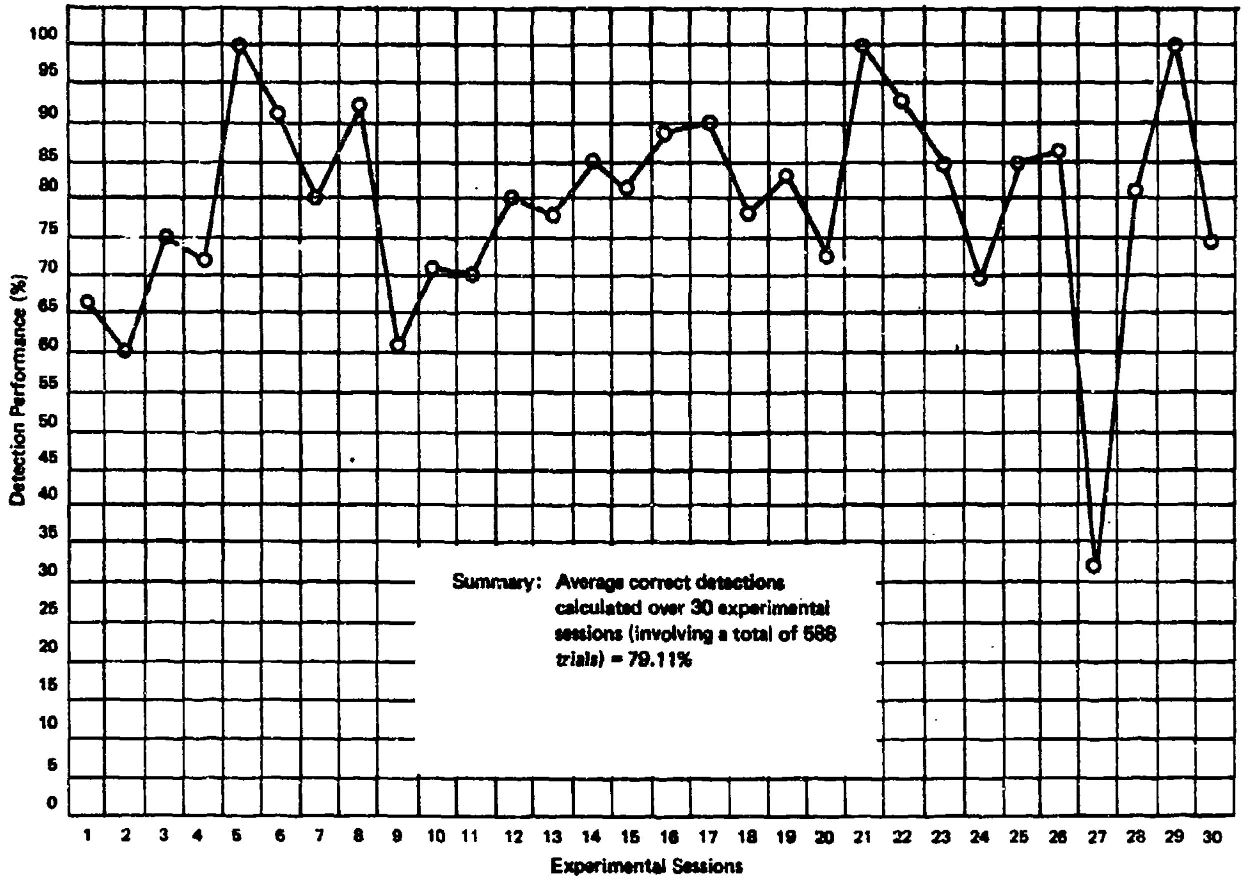


Animal
Norwegian
Elkhound
(Erica)

O—O = % correct detections per experimental session

Target Description Code	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I	G	H	I
Number of Trials per Experimental Session	18	12	14	18	12	14	18	12	14	18	12	14	18	12	14	18	12	12	18	12	12	18	12	12	18	12	12	18	12	12

Target Code: A = C-4 | D = Tetryl | G = M-15
B = Comp B | E = PETN | H = M-16
C = TNT | F = RDX | I = M-19

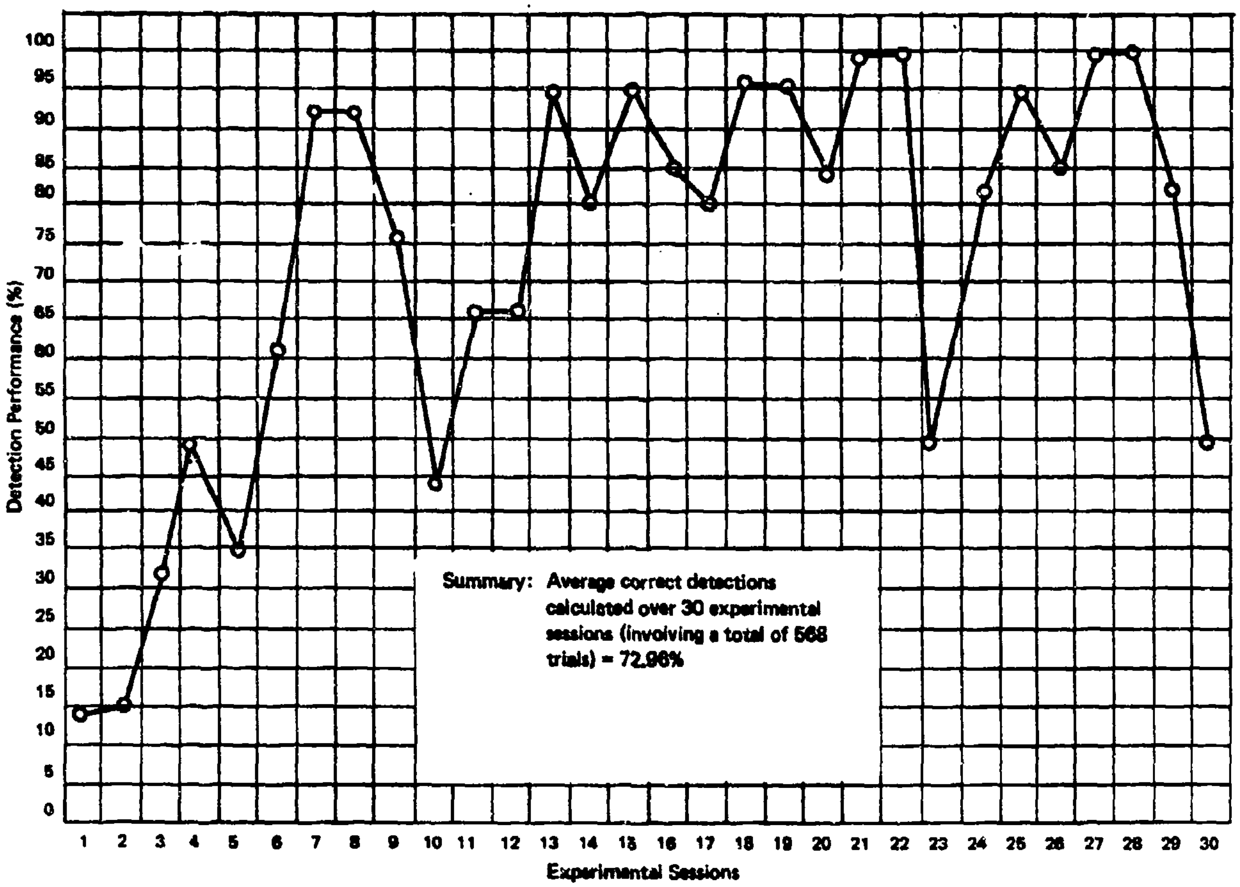


Animal
Welsh Corgi
(Taffy)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	G	G	H	I
Number of Trials per Experimental Session	12	20	16	15	5	24	15	16	31	32	20	20	22	20	16	29	20	14	26	16	15	26	27	20	20	15	15	16	14	14

Target Code: A = C-4 D = Tetryl G = M-15
B = Comp B E = PETN H = M-16
C = TNT F = RDX I = M-19

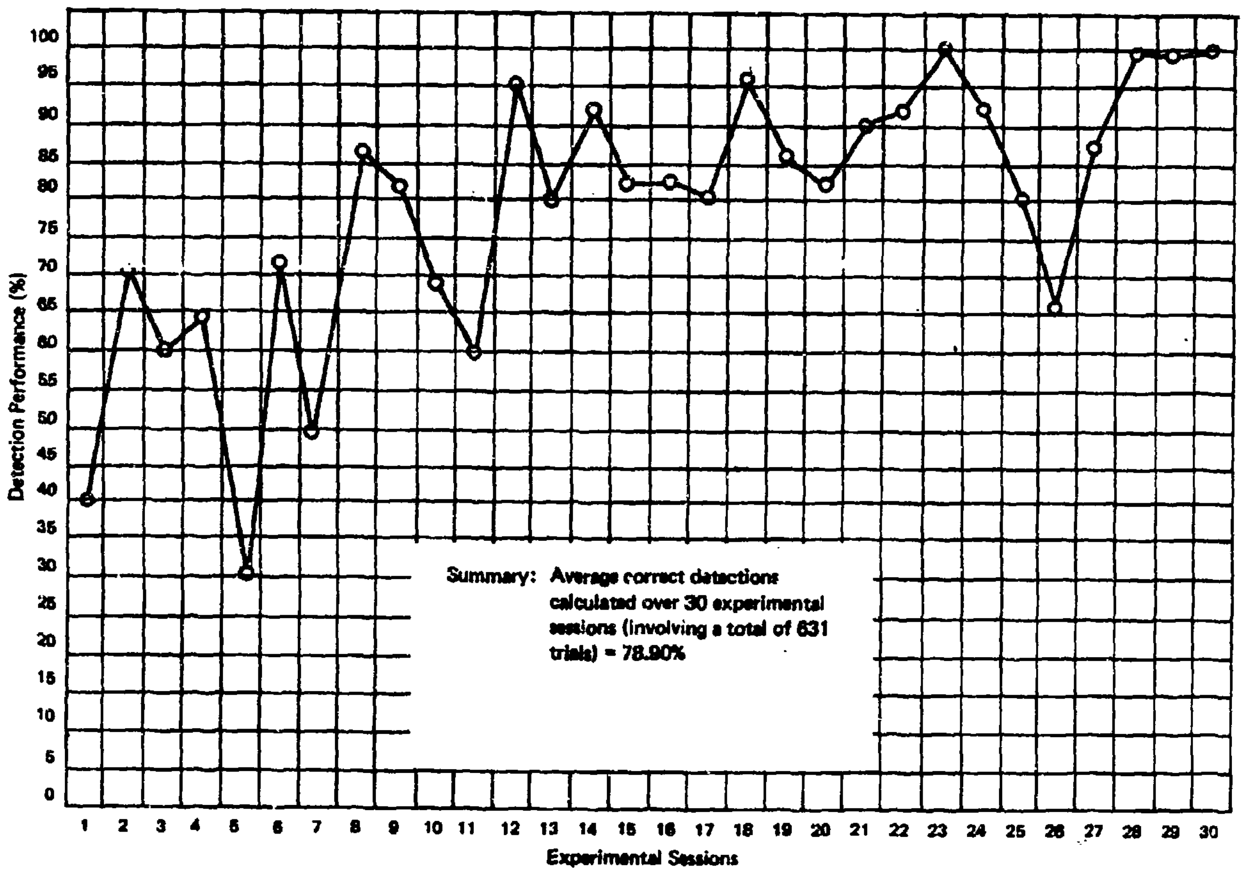


Animal
Welsh Corgi
(Taffy)

O——O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	G	G	G
Number of Trials per Experimental Session	17	20	19	10	10	8	16	25	25	19	21	18	20	20	20	20	25	30	20	25	19	20	10	17	30	20	15	15	16	18

Target Code: A = C-4 | D = Tetryl | G = M-15
B = Comp B | E = PETN | H = M-16
C = TNT | F = RDX | I = M-19

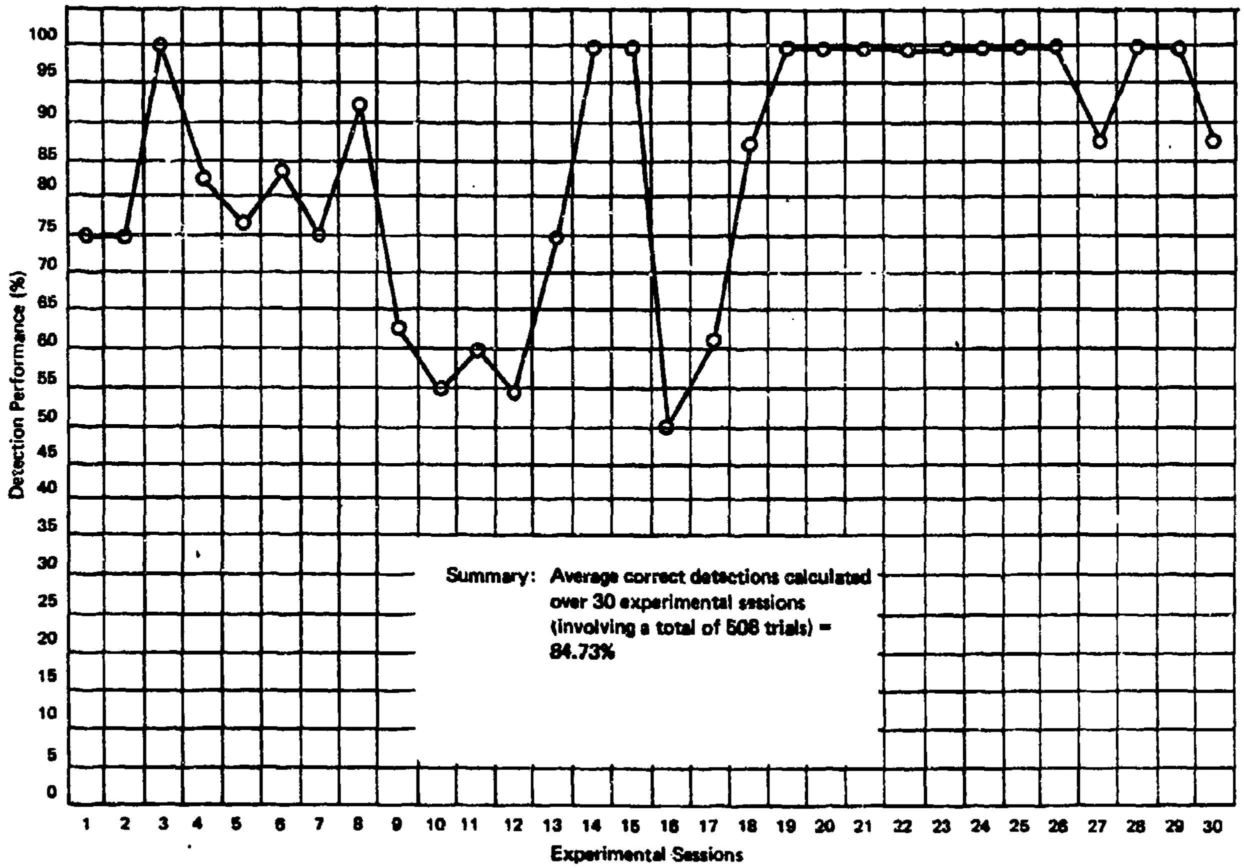


Animal
Welsh Corgi
(Taffy)

O——O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B·	B	B	G	G	G	H	I	G
Number of Trials per Experimental Session	10	10	15	15	10	18	8	15	28	29	15	20	20	25	30	30	30	30	30	30	30	30	30	30	15	16	18	12	14	18

Target Code: A = C-4, B = Comp B, C = TNT, D = Tetryl, E = PETN, F = RDX, G = M-15, H = M-16, I = M-19



Animal
Border Collie
(Salt)

O—O = % correct detections per experimental session

Target Description Code	A	A	A	A	A	A	A	B	B	G	H	I	G	H	I	G	I	G	H	I	G	H	I	G	H	I	G	H	I	G
Number of Trials per Experimental Session	20	20	9	6	30	25	20	30	30	20	14	18	18	12	14	12	14	18	12	14	18	12	14	18	12	14	18	12	18	18

Target Code: A = C-4 D = Tetryl G = M-15
B = Comp B E = PETN H = M-16
C = TNT F = RDX I = M-19

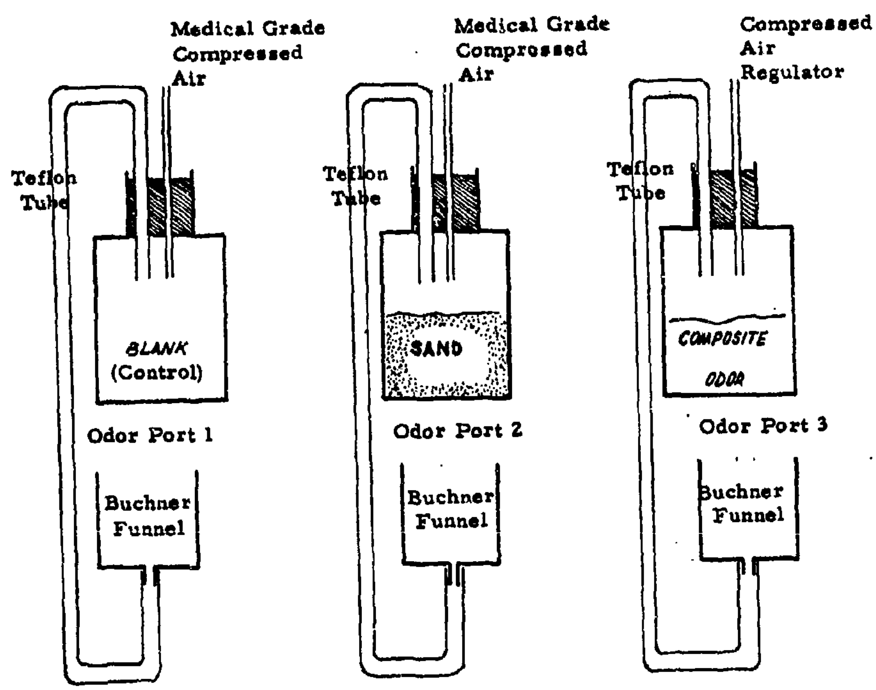
SPECIAL OLFACTORY SENSITIVITY STUDIES

At the request of the technical monitor, special studies were undertaken within the laboratory setting to:

(1) Determine odor or odor profile of mine objects which stimulate a conditioned response in dogs in laboratory and field tests

(2) Determine olfactory sensitiveness to these odors.

The laboratory odor profile selected for use consisted of sand, C4, ferrous metal and human scent. Because of the difficulty involved in training dogs to detect materials in dry sand, moist sand (15% water by weight) was used in the experiments reported. An olfactometer was developed for use in the laboratory study phase (see diagram in Fig. 20).



Note that the positions are interchangeable to prevent the animal from memorizing position of the target odor

FIGURE 20. Sketch of Olfactometer Developed for the Laboratory Studies

The olfactometer was subsequently modified to allow the odorous effluent discharged into the sampling odor ports to be exhausted outside the laboratory. This was done to prevent contamination of room air where the olfactometer was located with the test odor vapors. As can be seen in Figure 20, odor sampling ports were capable of being alternated among three positions. Each port delivered 10cc of compressed air/min. that had passed through gas diffusion bottles containing the selected odorous components. The standard odor (composite scent) contained 1 gm. C4, 2 gm. iron filings and 100 mg sebum mixed in approximately 70 gm. of moistened sand. Ambient conditions prevailed during test exercises.

In using the olfactometer, an alerting response (sit) given to the composite odor sample was reinforced with food. A false response given to either air or air and sand was corrected. Once the dog trainee reached an acceptable level performance, odors represented in the composite odor sample were individually added to the sand sample in subsequent tests. The composite sample was removed from tests only when it was necessary to arrive at certain conclusions during discrimination exercises. Dogs that were selective in responding to a certain odor or odor profile were tested on decreasing quantities of the odor stimulus to arrive at olfactory sensitiveness levels.

In using the olfactometer, the dog trainees were exposed to approximately 25 trials during a single olfactory test and were scored on their performance on each trial. Reliability of performance was measured in two ways: (1) number of false responses, i.e., sitting at either the compressed air or compressed air and sand odor ports, and (2) number of presumed samplings of the standard odor that did not stimulate the desired alerting (sit) response. While in the basic training phase, the trainer frequently cued the dog on the standard odor so as to alert the dog to the presence of the standard odor. However, cueing was not utilized during the experimental procedures.

The results of two German Shepherds (Jason and Egon) selected as early candidates for laboratory olfactory testing are presented in Table IV.

Table IV. Results of Olfactory Performance by Jason and Egan(Two German Shepherds)

Dog	Response to Target Odor		Response to Compressed Air Alone		Response to Compressed Air and Sand	
	# Times Failed to Alert	Correct Detections	# False Sits	Total # Exposures	# False Sits	Total # Exposures
Jason	12	75	7	49	6	48
Egon	27	72	6	78	1	64

As indicated earlier, it was of experimental interest to assess the ability of dogs to respond to component elements of the composite explosive odor. Fortunately, the individual components of a composite sample which is representative of a buried mine object can be identified when a trained dog on successive olfactory trials responds by alerting on the odor component of interest. In exploring this during the laboratory studies, dogs were first trained by food reinforcement to alert on the composite mine odor which contained approximately 75 grams of moist sand (15-20% water), 1 gm of C4 explosive, 2 gms of 40 mesh degreased iron filings and 0.040 gms of sebum extracted with acetone from human skin swipes. During the experimental training sessions, positive responses and negative responses to the mine object odor (composite odor) were recorded as a measure of the dog's olfactory sensitiveness. An air sample from a compressed air tank and dirt similar to that contained in the composite odor sample were used as negative controls in the three-choice discrimination tests described earlier. A response to the dirt sample was presumed to indicate the lack of differentiation between the composite odor and the negative control during a particular trial. More than a chance response to the air blank (control) was presumed to indicate that the dog was confused.

During the course of the study, five dogs (one Poodle, two German Shepherds, and two Labrador Retrievers) were exposed to the individual odors from C4/sand, iron/sand and sebum/sand and a combination of C4/iron sand, C4/sebum sand and iron/sebum sand. An alerting response made to any of these odor profiles served to indicate the particular material presumed to serve as the olfactory stimulus.

The results of these experiments are summarized in Table V. For the most part, the dogs usually required a combination of two odors to serve as a stimulus to initiate the desired alerting response. It appears from these results that the age of the samples and moisture content of sand are important variables. This may be related to the information of iron oxides when iron filings are added to moistened sand. These experimental results also indicate that when C4 alone is added to the sand sample, the sample must age for longer than 4 hours in order to permit sufficient C4 vapors to accumulate in the sand. However, when C4 and iron were added to the wet sand, the combination of odor elements was sufficient to induce the alerting response among all trained olfactory dogs—even though the sample was only 4 hours old. It is interesting to note that two of the dogs (identified in Table V as Linda and Egon) were capable of selecting each individual odor component in the composite sample and using it as a cue for rendition of the alerting response. The remaining dogs require the presence of the combination of composite odors for rendition of the alerting response. There is some evidence, however, that this differential ability is due not so much to innate olfactory acuity but to native intelligence. Both Linda and Egon are exceptionally intelligent dogs.

Table V.

	Description of Sample Odor	Dog's Response When Exposed By Olfaction To Components Representative Of A Mine Object Buried In Sand				
		Linda	Egon	Bobby	Casey	Jason
1.	4 hour old iron sample in dry sand 4% moisture	–	–	–	–	–
2.	48 hour old iron sample in dry sand 4% moisture	+	–	–	–	–
3.	96 hour old iron sample in dry sand 4% moisture	+	+	–	–	–
4.	24 hour old iron sample in moist sand 15% moisture	+	+	–	–	–
5.	48 hour old iron sample in moist sand 15% moisture	+	+	–	–	–
6.	96 hour old iron sample in moist sand 15% moisture	+	+	+	–	–
7.	4 hour old C4 sample in moist sand 15% moisture	–	–	–	–	–
8.	48 hour old C4 sample in moist sand 15% moisture	+	+	–	–	–
9.	96 hour old C4 sample in moist sand 15% moisture	+	+	–	–	–
10.	4 hour old sebum sample in moist sand 15% moisture	+	+	–	–	–
11.	48 hour old sebum sample moist sand 15% moisture	+	+	–	–	–
12.	4 hour old iron/sebum sample moist sand 15% moisture	+	+	–	–	–
13.	48 hour old iron/sebum sample moist sand 15% moisture	+	+	+	+	–
14.	4 hour old C4/sebum sample moist sand 15% moisture	+	+	–	–	–
15.	4 hour old C4/iron sample moist sand 15% moisture	+	+	+	+	+

\- indicates failure to detect target
\+ indicates success in detecting target

Results of additional experiments are contained in the following six tables. Table VI contains raw performance data obtained during the actual training sessions for the five dogs listed below.

Name	Breed	Sex
Linda	Standard Poodle	Female
Jason	German Shepherd	Male
Egon	German Shepherd	Male
Bobby	Labrador	Female
Casey	Labrador	Female

Table VII contains a summarization of the data presented in Table VI. This data suggests that all the dogs used in the experiment improve according to the number of sessions they are exposed to. Table VIII summarizes the dog's performance on dry sand at 4, 48 and 96 hours. With regard to this data, since iron filings is the odor profile tested, oxides might account for positive reactions shown in the aged samples. Table IX presents results of concurrent olfactory preference testing of composite odor, iron filings and air. From these results, it can be seen that Linda, the standard Poodle, showed no difference in percentage of response to composite odor and iron filings. However, Egon showed a preference to the composite odor 86% of the time. Table X summarizes the results of the dog's performance when olfactory samples are prepared with wet sand. It appears obvious in this case that wet sand enhances the release of vapors in that the dogs showed significant increase in detection abilities. This phenomenon has also been observed in the field under various climatic conditions. It may be partially explained by the fact that moisture hastens the formation of metal oxides, which could constitute effective detection cues. It could also be partially explained by the fact that moisture facilitates the transport of explosive odor constituents to the surface where they are detachable by the dog.

Table XI rates the dogs according to selected indicators related to (1) overall performance proficiency, (2) olfactory sensitivity, (3) olfactory discrimination ability, and (4) behavioral stability.

Table VI.

Olfactory Training Performance of
Egon, Jason, Linda, Casey and Bobby

Dog	Test No.	Composite Odor Pass	Composite Odor Positive response	Sand Pass	Sand False Resp.	Air Pass	Air False Resp.
Egon	1	8	26	23	1	19	1
	2	5	25	18	1	15	1
	3	3	25	13	1	14	0
	4	1	25	13	0	15	0
	5	4	25	15	0	15	2
	6	0	25	13	0	13	2
Total		21	151	95	3	92	6
Jason	1	4	25	18	0	16	0
	2	3	23	22	1	18	0
	3	6	24	18	2	16	0
	4	1	25	16	0	16	0
	5	1	26	14	1	16	0
	6	2	24	29	0	16	0
	7	0	25	20	1	14	0
Total		17	172	137	5	112	0
Linda	1	0	25	11	3	10	3
	2	1	15	8	0	7	0
	3	5	22	22	5	18	0
	4	1	25	13	0	12	0
	5	2	25	14	0	12	0
	6	0	25	13	1	15	0
	7	1	25	15	0	9	0
Total		10	162	96	9	83	3
Casey	1	5	14	17	3	17	2
	2	7	10	13	4	15	0
	3	11	27	22	4	20	8
	4	4	32	22	1	19	3
	5	6	30	18	1	17	2
	6	7	25	25	1	12	6
	7	2	30	23	0	19	0
Total		42	168	140	14	119	21
Bobby	1	3	15	22	1	20	2
	2	4	20	17	4	14	5
	3	10	20	18	7	22	1
	4	7	14	17	9	21	2
	5	12	19	21	3	17	6
	6	8	26	25	4	25	6
	7	4	17	25	4	26	1
	8	7	23	21	0	21	2
	9	9	28	21	10	17	1
	10	3	13	17	1	19	0
	11	4	20	13	7	14	1
Total		71	215	217	50	216	27

Table VII.

Average Percentage of Composite Odor Detection Proficiency and Percentage of Probable Error in Early Discrimination Training

Dog	Cumulative Cues	Trials with no Cues	Detection Proficiency comp. odor	Probability of responding to sand	Probability of responding to air	False Response Rate
Linda	6	172	94.0%	.09	.035	6.5%
Jason	13	258	91.0%	.035	0	2.0%
Egon	29	221	87.5%	.03	.06	4.5%
Casey	41	210	79.5%	.09	.15	12.0%
Bobby	93	296	75.5%	.185	.11	15.0%

Table VIII

Detection proficiency of composite odor in dry sand and percent response to the presence of iron and sand odor profile of dogs at 4, 48 and 96 hours.

Dog	Detection proficiency to composite odor	Probability of responding to sand	Probability of responding to air	Detection Proficiency to iron and sand odor
Results of dogs exposed to samples aged 4 hours				
Egon	75%	0	.08	0
Jason	Did not test			
Linda	100%	0	0	0
Casey	92%	.09	.14	0
Bobby	97%	.01	.13	0
Results of dogs exposed to samples aged 48 hours				
Egon	94%	.14	0	0
Jason	92%	.33	0	0
Linda	80%	0	0	100%
Casey	Did not test			
Bobby	Did not test			
Results of dogs exposed to samples aged 96 hours				
Egon	68%	0	0	100%
Jason	74%	0	.11	0
Linda	67%	.07	0	100%

Table IX

Three choice test to determine the difference between response rate to composite odor and iron when used in the same test.

Dog	Detection proficiciency for composite odor	Detection proficiency for iron	Probability of responding to air
	Dry sand samples aged 4 hours		
Egon	33%	0	0
Linda	100%	0	0
Casey	92%	14%	0
Bobby	100%	0	0
	Dry sand aged for 48 hours		
Egon	88%	0.9%	0
Jason	80%	0	0
Linda	100%	100%	0
	Dry sand aged for 96 hours		
Egon	88%	14%	.17
Linda	100%	100%	0

Table X

Results of the dog's performance when olfactory samples were prepared with wet sand (20 to 30% moisture) and allowed to age 4, 48 and 96 hours.

Dog	Detection proficiency for composite odor	Probability of responding to sand	Probability of responding to air	Detection proficiency to iron sand odor
	Wet sand samples aged 4 hours			
Egon	100%	.05	.08	.86
Jason	100%	.10	.09	0
Linda	96%	0	.06	1.00
Casey	92%	.03	.12	0
Bobby	97%	.13	.08	0
	Wet sand samples aged 48 hours			
Egon	97%	0	0	.75
Jason	96%	0	0	0
Linda	100%	0	0	1.00
Casey	96%	.03	.13	0
Bobby				
	Wet sand samples aged 96 hours			
Egon	91%	0	0	.75
Jason	94%	0	.03	0
Linda	97%	0	0	1.00
Casey	100%	0	0	0
Bobby	95%	.06	0	.38

Table XI.

Relative placement of dogs in presumed olfactory acuity and stability of behavior (the latter being represented by the lack of confusion or lapses in concentration).

1. <u>Olfactory Acuity</u>

   a. Sensitiveness

      1. Linda
      2. Egon
      3. Jason
      4. Casey
      5. Bobby

   b. <u>Discrimination Ability</u>

      1. Linda, Egon
      2. Jason, Casey
      3. Bobby

2. <u>Behavior - Stability</u>

   1. Linda
   2. Egon
   3. Jason, Casey
   4. Bobby

The indicators used in developing the above relative performance ratings were proficiency of detecting and responding to the standard odor (on composite mine sample). This was presumed to represent olfactory sensitivity; false response to only sand was presumed to indicate lack of discrimination; while false response to the air blank (control) use was presumed to indicate lapses in concentration or confusion.

OLFACTORY SENSITIVITY TESTING
(Using Melted TNT With Helium As The Carrier)

In an effort to develop a more precise means of quantifying the detection capabilities of the detector dogs, the project staff devised a method that will enable a more direct measurement of the concentration of TNT molecules contained in a mixture of helium gas presented to the dog. The method is limited to exhausting a presumed concentration of 10^{12} molecules per second from melted commercial grade TNT at 84°C to 87°C. TNT was selected for explosive odor vapor tests in preference to C4 because previous research has revealed a much higher probability of detection in the case of the latter substance.

The procedure developed for enhancing quantification of the experimental procedure uses a thermostatically controlled oven large enough to hold a 1 gram sample of melted (80°C) TNT contained in a glass sample bottle. Helium gas at flow rates of 50-60cc to 600cc per minute is introduced through a teflon tube into the bottle which contains the melted TNT. An exhaust tube then allows the effluent (He + TNT vapors) to pass to an odor port where trained dogs are exposed to the sample.

The upper portion of the system's exhaust tube contains a condensate collection tube for holding the distillate which evolves from TNT melted at 80°C. This substance is amorphorous and waxy to the touch. Since upon microscopic examination of the exhaust tube, TNT crystals have been conspicuously absent, it is presumed that a vast majority of TNT molecules diluted in the helium gas reaches the odor port for the dog to sample. In fact, it seems probable that because of removal of a relatively large amount of the waxy substance from the effluent, the TNT odor profile becomes even more defined. It is interesting to note that the collected impurity is nearly equal in weight to that of the TNT vapor evolved. For example, a total loss of 4 mg from the sample bottle was generally seen to represent 2 mg of TNT and 2 mg of the waxy substance that collects in the condenser. Therefore, with this system, computations are based only on the TNT loss (2 mg) and not the total sample weight deficit (4 mg).

Although there appears to be a relatively wide variation of TNT loss among tests, the significance of these variations in terms of concentration of molecules is felt to be slight. For example, in using the

lowest value, 0.06mg/TNT lost/hour, and the highest value, 0.190mg lost/hour, compared to the average value, the concentration of molecules is as follows:

$$\text{mg/sec.} = \frac{\text{mg TNT/hr.}}{3600}$$

$$\text{moles/sec.} = \frac{\text{mg/sec.}}{2.27 \times 10^5}$$

$$\text{molecules/sec.} = \text{moles/sec.} \times 6.023 \times 10^{23}$$

Therefore, a sample weight loss of .06 mg/hr. is equivalent to a release of 4.43×10^{13} molecules/sec. of TNT. Similarly, a loss of .124 mg/hr. and /190 mg/hr. corresponds to $9/15 \times 10^{13}$ and 1.40×10^{14} molecules/sec., respectively.

The lowest value (4.43×10^{13} molecules/sec.) is informative with respect to canine olfactory sensitivity because trained dogs experienced little or no difficulty detecting TNT vapors under these test conditions.

Since 1.60×10^{-4} gm. of He occupies approximately 1cc at 25°C and 754 mm Hg, the number of molecules of He per second at a flow rate of 60cc per minute may be calculated as follows:

$$\text{moles/sec.} = 1.6 \times 10^{-4}\ \text{gm/sec.} \times 1\ \text{mole/4 gm.},$$

molecules/sec. = moles/sec. x 6.023×10^{23} molecules/mole, which is equivalent to 2.4×10^{19} molecules/sec. At a flow rate of 600cc/min., 2.4×10^{20} molecules/sec. are released. Thus at a flow rate of 1 cc/sec., 2.4×10^{19} molecules/sec. of He are mixed with 9.15×10^{13} molecules/sec. of TNT yielding 1 TNT molecule per 2.62×10^5 molecules of He. At 10 cc/sec., this ratio is 1 TNT molecule per 2.62×10^6 molecules of He. There is some assurance that computed value is a good estimate of the quantity of TNT presented to the dog by this system, assuming that the TNT weight loss and condensation are relatively constant.

In repeated tests conducted over 5 to 24 hour periods at 84°C to 87°C with a helium flow of 30cc to 60cc per minute, the computed hourly weight loss in most cases has been fairly consistent. We were unable to derive an explanation for the lower values of .07 and .06 mg

that are included in Table XII. An average of the six values does, however, provide a constant by which concentrations of TNT molecules can be computed per second.

Table XII
Variation in Sample Weight Loss

Test No.	Weight Difference
1	0.190 mg
2	0.160 mg
3	0.060 mg
4	0.154 mg
5	0.110 mg
6	0.060 mg

The average hourly weight loss equals 0.124 mg.; calculation of the 95% confidence interval indicates that the true value lies between 0.082 and 0.166 mg.

Without evidence to the contrary, this average loss rate was considered to be regulated by the temperature and not the flow rate of helium gas as long as it is between 10cc to 60cc per minute. A very high flow rate of helium gas into the sample bottle may create a turbulence which might cause a larger surface exposure of the TNT sample and hence a higher weight loss than the computed average value of 0.124 mg/hour.

An estimate of the olfactory capability of the dog is provided by the fact that dogs can accurately respond within approximately one second to the delivery of 9.15×10^{13} molecules of TNT mixed with 2.4×10^{19} molecules of He. However, since the actual number of TNT molecules arriving at the receptor is unknown, a more precise determination of TNT response thresholds requires further research.

During an extension of the above studies, a number of dogs were trained to respond to a commercial grade TNT composite mine object odor and to discriminate against soil and air negative controls. They were then challenged to detect TNT in the solid state and in the liquid state.

Table XIII.

Test Results of Olfactory Response and Behavior of 8 Dogs Exposed to TNT 80° - 85°C and Negative Control Odor Ports

Dog	% Positive Response	% False Response Control Bl. 1	% False Response Control Bl. 2	Test No.	Remarks
1. Jason	97	0	0	1	
	100	0	0	2	
	100	He↑ 0	0	3	No effect by He negative control
	96	He↑ 0	0	4	
	100	He↑ 0	0	5	
2. Linda	75	4	0	1	
	97	0	0	2	
	97	He↑ 0	0	3	No effect by He negative control
	100	He↑ 0	6	4	
	95	He↑ 4	0	5	
	100	He↑ 0	0	6	
	100	He↑ 0	0	7	
3. Egon	97	0	0	1	
	90	0	0	2	
	91	He↑ 0	0	3	No effect by He negative control
	94	He↑ 8	0	4	
	96	He↑ 0	7	5	
	100	He↑ 0	0	6	
	94	He↑ 0	0	7	
4. Casey	80	0	41	1	Confusion
	85	He↑ 4	8	2	Minor confusion. Some inability to discriminate TNT
	96	He↑ 0	0	3	Positive evidence of learning
	95	He↑ 0	0	4	Positive evidence of learning
	100	He↑ 0	0	5	Positive evidence of learning
	100	He↑ 0	4	6	Positive evidence of learning
5. Stan	40	0	0	1	Lack of olfactory sensitivity behavior unaffected
	72	4	4	2	
	88	0	0	3	
	84	He↑ 30	0	4	Inability to discriminate or else the dog was cueing on the gas control
	92	He↑ 4	0	5	Positive evidence of learning
	90	He↑ 0	0	6	Positive evidence of learning
	100	He↑ 0	0	7	Positive evidence of learning
	96	HE↑ 0	0	8	Positive evidence of learning
6. Flip	80	0	6	1	
	87	3	12	2	
	83	0	5	3	
	85	He↑ 13	8	4	Some difficulty discriminating TNT
	100	He↑ 0	0	5	Positive evidence of learning
	100	He↑ 11	5	6	
	95	He↑ 0	5	7	
	93	He↑ 11	0	8	Partial regression
7. Bobby	82	25	20	1	Confused behavior
	70	0	35	2	Confused behavior
	61	He↑ 16	24	3	Confused behavior, could not discriminate TNT
	84	He↑ 5	0	4	Positive evidence of learning
	96	He↑ 0	0	5	Positive evidence of learning
	100	He↑ 0	8	6	Positive evidence of learning
8. Cad	Results poor, dog untrainable for this task.				

The solid TNT olfactory samples utilized weighed between 0.5 gm and 1.0 gm and were contained in sterilized glass bottles that had two openings for the installation of 1 mm diameter teflon tubes for the delivery of helium gas and for exhausting available TNT vapor or particulates. The effluent gas vapor stream was delivered to an olfactometer such as described earlier at a rate of 10cc per minute or 0.17cc per second. This is equivalent to (or less than) the time it takes a dog to sniff or sample an odor port.

The test dogs were first submitted to brief periods of training on the solid TNT before introducing the liquid TNT tests. The results of these tests are presented in Table XIII. Training on the solid TNT established the fact that the dogs were able to respond to TNT in its natural state and that the deposited residue discussed earlier was not a critical component of the olfactory stimulus complex.

The fact that the dogs did not perform as well as solid TNT samples as they did on liquid samples probably was due to the vastly reduced number of molecules released from the lower temperature (solid) material. However, with additional training on solid samples, performance improved to a 95% level of correct detections.

During the experimental study, it was observed that TNT heated to the melting point (80° - 85°C) averaged a weight loss of .124 mg per hour when the helium gas flow rate was maintained at 30 or 60cc per minute. This represented an average of 9.15×10^{13} molecules of TNT that were removed from the heated TNT sample each second. Because of the probability that many of the computed number of molecules evolving from the heated TNT did not reach the odor ports and considering the dilution of the molecules in the carrier gas helium and in the ambient air inspired when the dog sniffed the sample, it seems reasonable to assume that the number of molecules that stimulated the olfactory receptors was less than 9.15×10^{13}.

In considering the data contained in Table XIII, it should be remembered that except for the 3 or 4 brief training periods on solid TNT only, all previous olfactory training and testing was conducted using TNT samples in combination with soil, iron or sebum.

The results obtained during the melted TNT test phase show progressive improvement of the dog's olfactory sensitivity, an event which is usually related to an increase in the number of test exposures. Here,

improvement is indicated by the % positive responses to the odor of TNT on a single inspection and a corresponding absence of false responses to the negative controls. Note that the data in Table XIII do not reflect positive responses on a second inspection. During the test, dogs would first examine all test odor ports and then return and respond to positive odor port much as if they were analyzing the olfactory differences among the samples. Had the positive responses on the second exposure been counted during the test, most of the dog's % response rate would approach 100!

The % false responses were recorded on the presumption that whenever a large number were registered, such signified confusion resulting from the fact that the dog could not discriminate the TNT odor. Indeed, the inability of some dogs to detect the presence of TNT in the first two or three tests seemed in practice to be followed by confusion. This in turn appeared to influence the dog's behavior, causing a significant increase in the number of false responses. Other dogs, however, appeared more stable. Their performance decrement, when exposed to the vapors from liquid TNT in the first two or three tests, was apparently caused by a true lack of olfactory sensitivity, without any adversive effect on behavior being observed. The rate of false responses in the more stable dogs was negligible.

It was observed that dogs can become more sensitive to the vapors from TNT with repeated testing. Thus, in effect, each test in the experiment became a training session in that all dogs generally became reliable olfactory detectors of liquid TNT in quantities of less than 3.44×10^{-5} mg.

Use of the special olfactory chamber employing melted TNT and helium transport (as described above) was explored because it has the potential for increasing the accuracy of determining the precise amount of odor substance impinging on the animal's olfactory apparatus. However, by using melted TNT--instead of solid explosives held at a temperature typical of the operational environment(s)--the system did introduce the possibility of variables operating which would not be reflected in the actual detection situation (where solid--not melted explosives--are employed). For this reason, two approaches appeared indicated: (1) a chamber employing melted TNT to help establish limits of the animal's sensitivity under precisely controlled laboratory conditions; (2) a chamber employing solid TNT. The idea here is to obtain as accurate information as possible upon olfactory sensitivity, using

explosives in their normal state, controlling for such factors as temperature and humidity as they are apt to be encountered in various operational localities around the world. To meet this requirement, a special solid explosive olfactory chamber was developed. However, due to limited financial resources, it was not placed into operation as part of the contractual effort being reported herein.

Based upon the results of this special study, conducted under the conditions specified, it seems apparent that trained dogs can detect amounts of TNT on the order of 1 part per 2.62×10^6 parts of He gas. Also, previous studies using TNT at 22°C suggest that the dog's olfactory sensitivity to this grade of TNT is considerably greater than the value estimated in these calculations.

TRAINING OF CANINE PROGENY: INTERIM PROGRESS REPORT

In order to experimentally assess potential techniques for increasing the efficiency of animal training procedures, a program of investigation has been initiated to determine the effectiveness of mimicry in the training of animal progeny for detection of buried explosive ordnance devices. Briefly, the general experimental strategy entails the training of selected mature dogs to a detection proficiency of 80% or greater by means of conventional operant conditioning procedures. These animals will then be bred, and the resulting progeny will be divided into matched "Mimicry" and "Control" groups. Each member of the Mimicry group will be required to imitate the detection performance of its trained parent on a standard set of problems in order to receive its daily dietary intake after weaning. Control group animals will be trained on the same set of problems according to conventional techniques. Statistical comparisons of Mimicry vs. Control group performance on such dependent measures as rate of task acquisition, asymptotic detection proficiency, and degree of performance variability will permit an objective evaluation of the contribution of maternal mimicry with respect to the expediting of detection training.

The procedural protocol outlined above requires initial detection training of potential parent animals to a stable level of detection proficiency. The procedures being employed during this earliest phase of training are similar to those developed and found successful in previous olfactory detection programs. Briefly, measured samples of the target substance are placed into a small, odor-sterile glass bottle fitted with a metal lid, the latter perforated by small holes to permit effusion of odor elements.

The bottle (positive stimulus) is placed on the floor along one wall of the training room and its position randomly exchanged with two empty, but otherwise identical, jars which serve as controls. All trials commence at a standard point on the opposite side of the room with the animal sitting at the handler's side. Upon initiation of a trial, the dog is reinforced (praise followed by a food reward), for seeking, identifying, and sitting at the locus of the positive stimulus.

To control for potential odor cross-contamination all bottles are washed and then sterilized at 350°F. for twenty minutes prior to each training session. Following sterilization, the bottles are wrapped with masking tape to assure that the animals cannot identify the positive sample by visual inspection of the contents.

Each dog is run approximately 50 trials per day, and data being collected include: percentage correct responses, percentage passes, percentage false responses, and latency of correct responses (time required for a correct detection per trial.)

Upon attainment of a stable performance criterion of 90% or greater correct detections of laboratory discrimination training stimuli, the animals are advanced to detection of M-16 antipersonnel land mines. Furthermore, during more advanced stages of training, an increasing proportion of each dog's daily ration is scheduled for delivery as rewards for correct performance. It is felt that the latter procedure enhances the biological significance of the search and detection task thereby assuring consistent daily motivation.

To date, eight female AKC-registered dogs have been acquired and entered into the experimental protocol:

Calamity Jane (German Short-haired Pointer)
Cher (Labrador Retriever)
Curly (Labrador Retriever)
Delilah (Bloodhound)
Gypsy (Labrador Retriever)
Topsy (Labrador Retriever)
Unis (German Shepherd)
Zero (German Shepherd)

All project dogs have received a course in basic obedience, and, with one exception, all animals are making normal progress with regard to explosive detection training tasks. Data for the month of June, 1974 (most recent complete monthly data block), reveal an overall correct detection rate of 85.5% with corresponding pass and false response rates of 9.0% and 5.5% respectively (computed on the basis of approximately 5,200 total training trials).

Figures 1-7 provide a more detailed summary of each dog's progress to date and depict percentages of correct, pass, and false responses as a function of month of training with selected laboratory olfactory discrimination training stimuli (either small samples of pure Composition B or defused M-16 antipersonnel land mines, depending on stage of training attained). As may be seen in these figures, all animals for whom data are presented are making satisfactory progress as of this writing. It should be noted the periods represented in Figures 1-7 are routinely preceded by a 6-8 week interval of preliminary training during which no meaningful data of a quantifiable nature may be collected. Also, only two monthly performance summaries are available for Figures 6 and 7 since the relevant dogs (Unis and Zero) were acquired relatively recently.

No data have been presented for one animal (Cher) since this dog failed to successfully master even the most rudimentary olfactory discrimination tasks. The latter factor, compounded by undesireable behavioral problems, resulted in a decision to terminate further experimental activities with this animal.

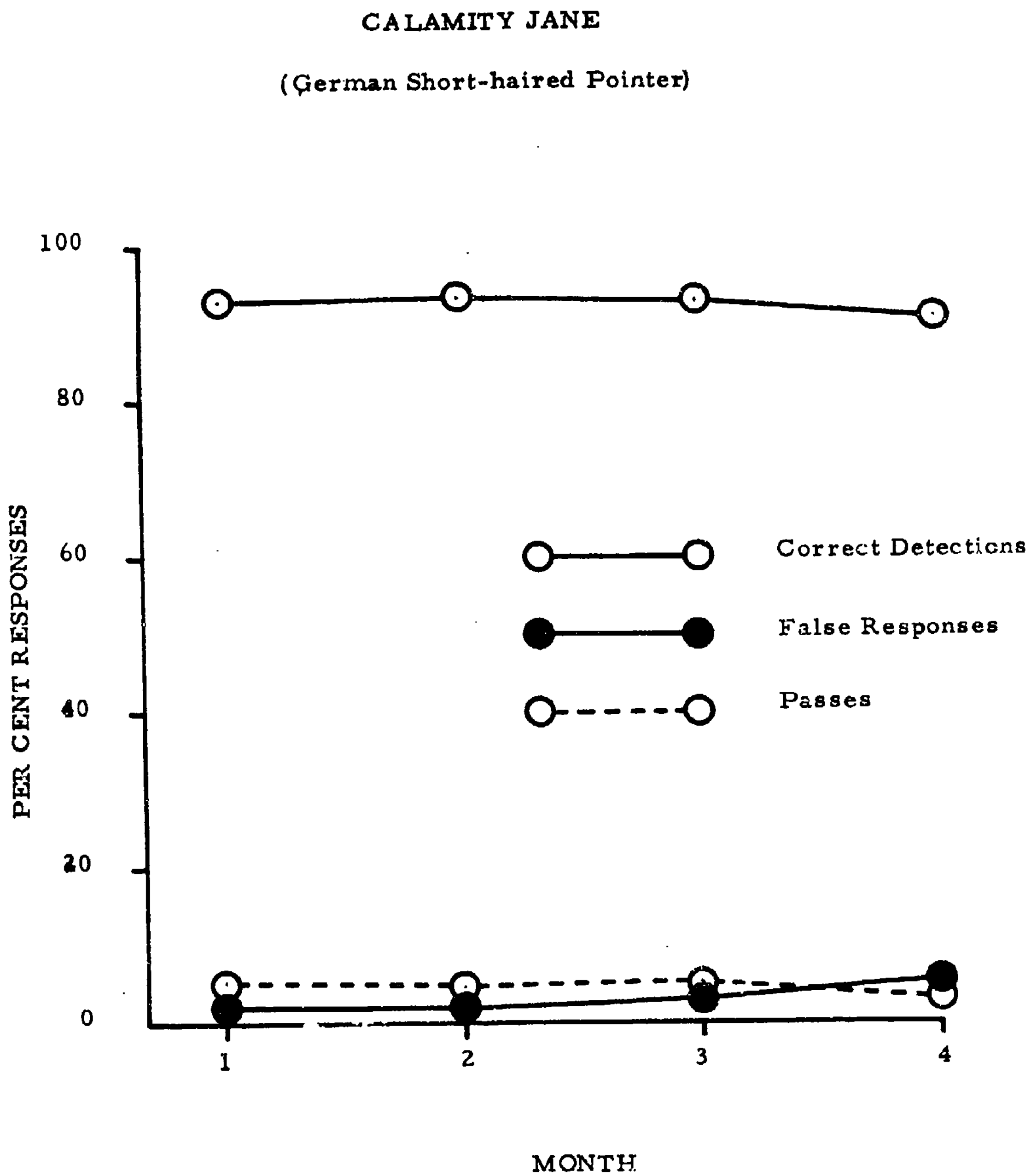


Fig. 1. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

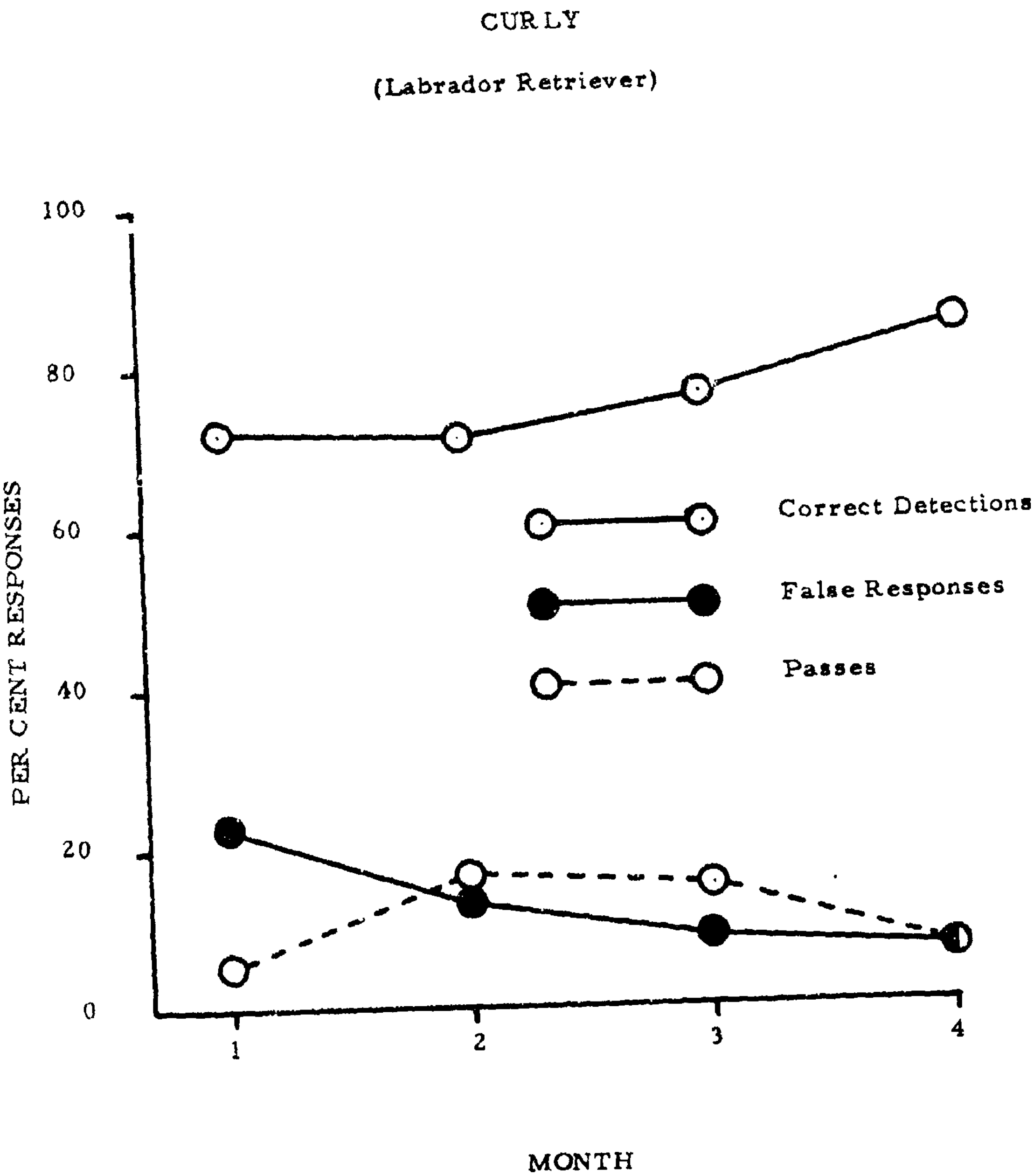


Fig. 2. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

DELILAH

(Bloodhound)

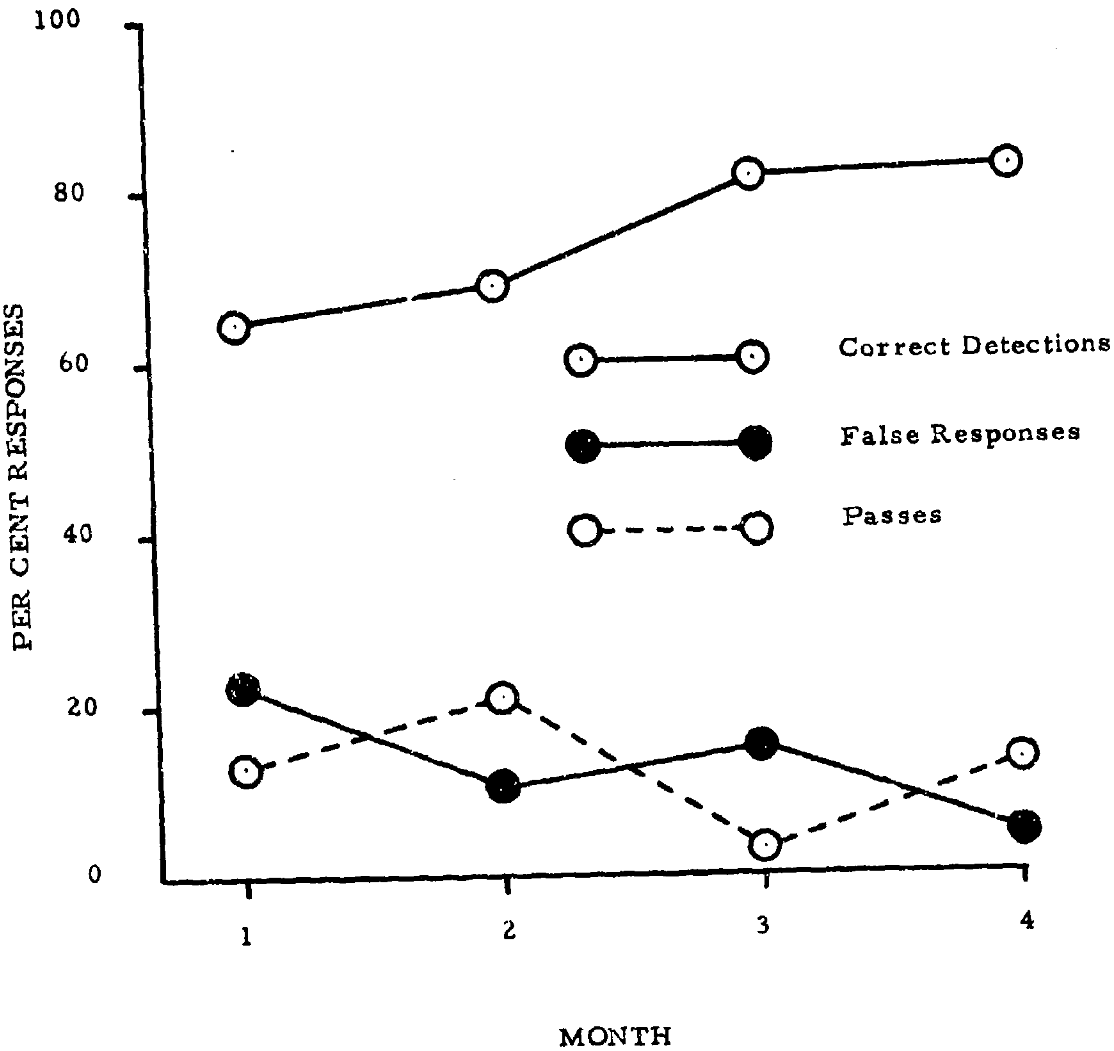


Fig. 3. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

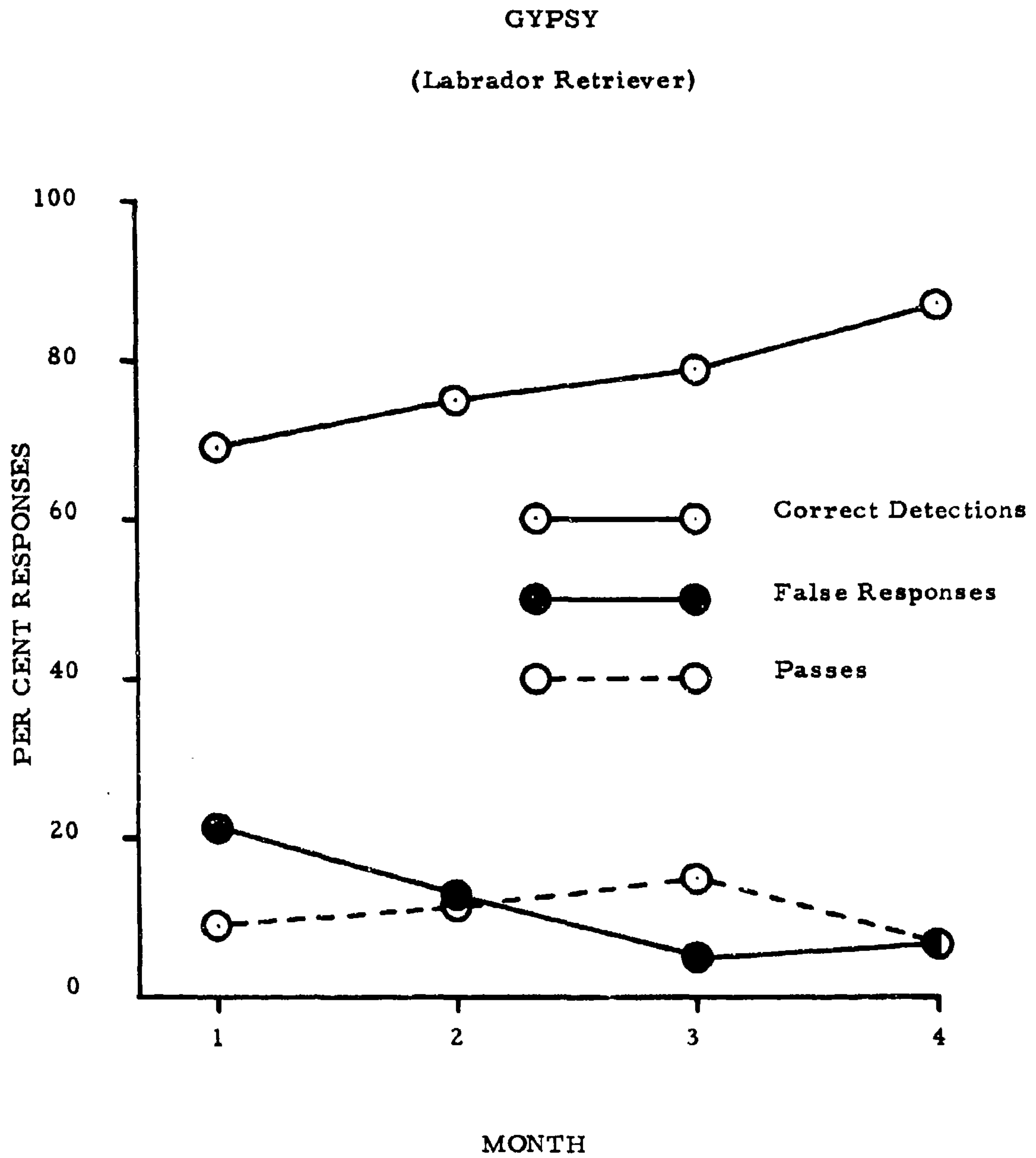


Fig. 4. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

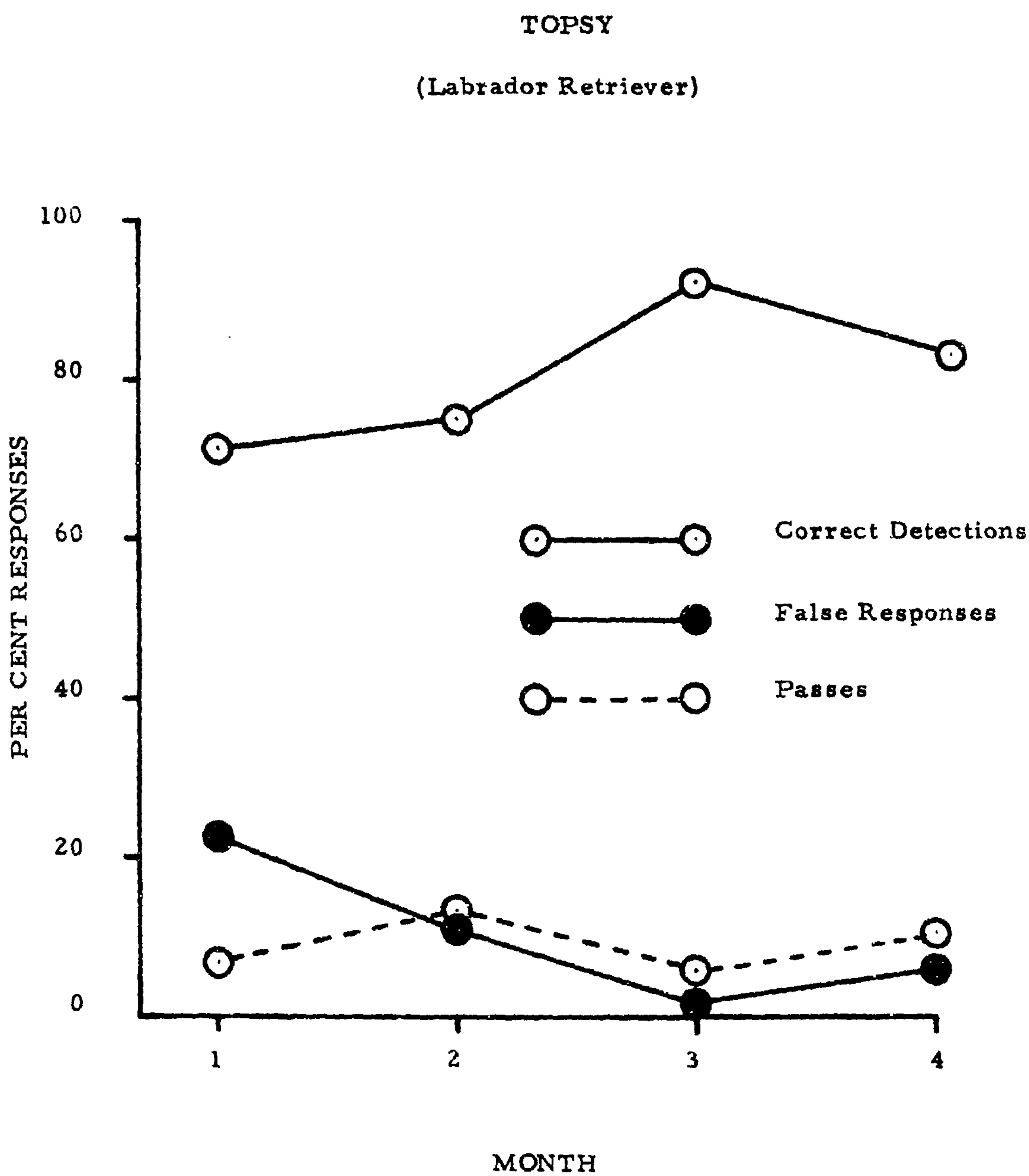


Fig. 5. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

UNIS

(German Shepherd)

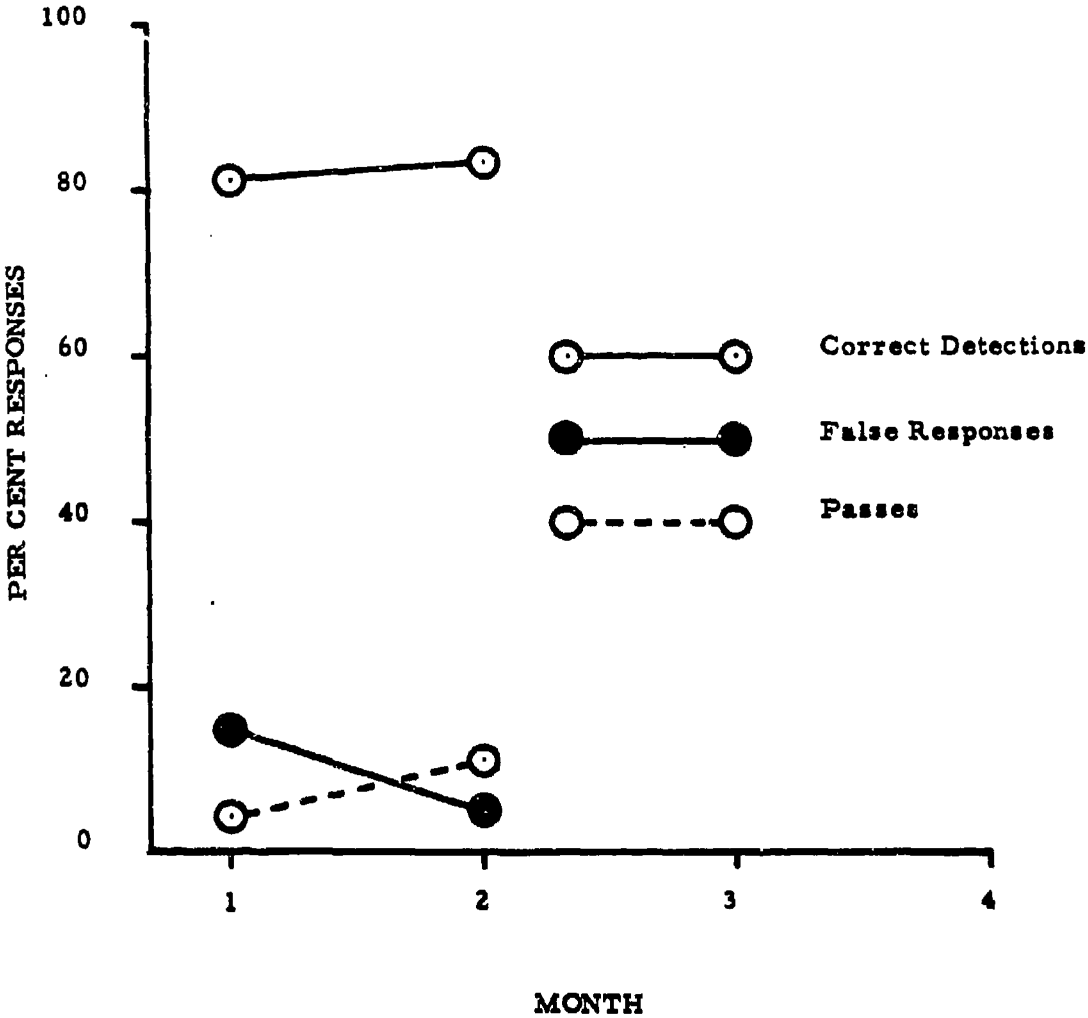


Fig. 6. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

ZERO

(German Shepherd)

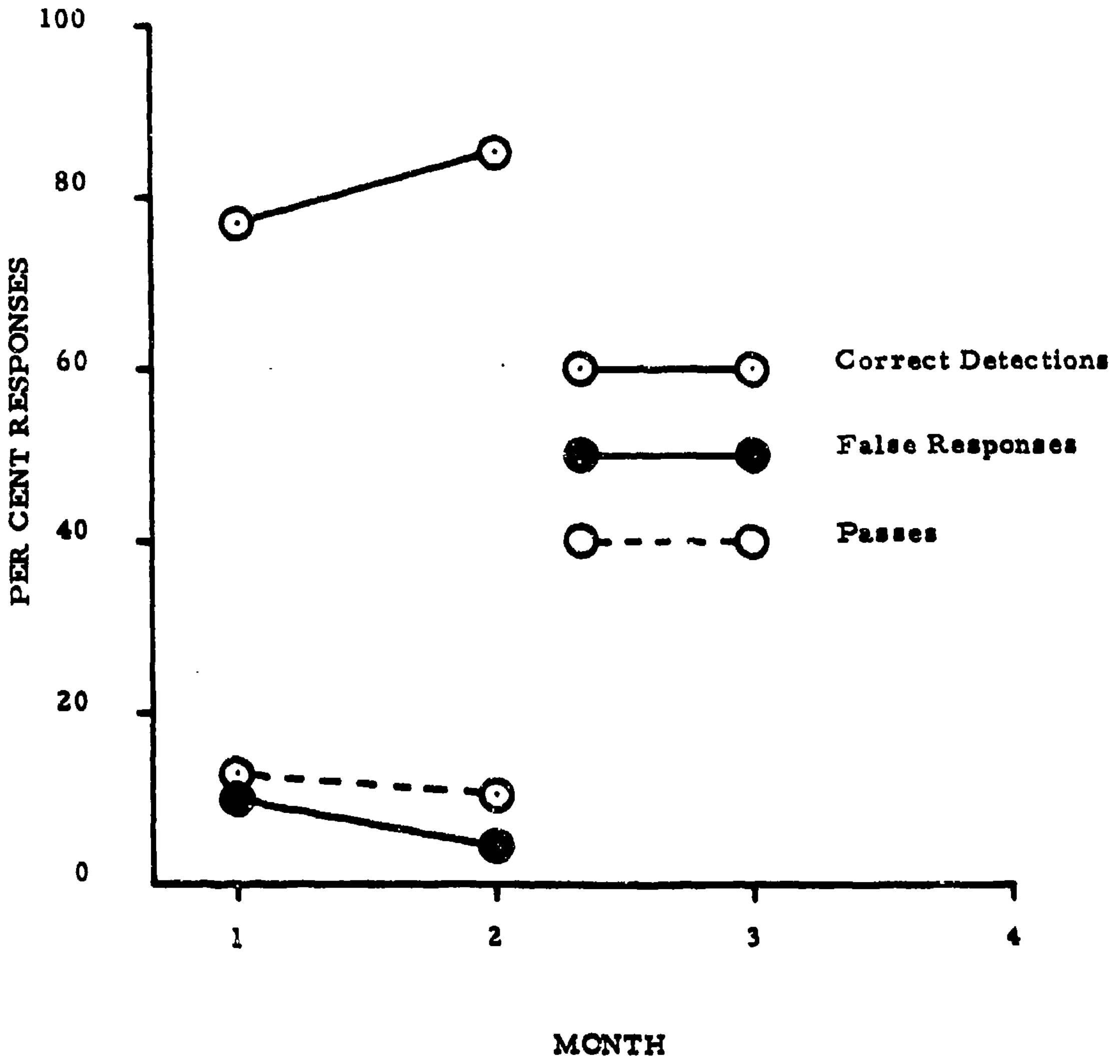


Fig. 7. Percentages Correct, False, and Pass responses as a function of month of training with selected laboratory discrimination training stimuli.

As of the date of this report, six of the seven current project animals have come into heat and have been bred to suitable AKC-registered studs. Litters of pups are expected at intervals ranging from two to approximately eight weeks.

The female German Shepherd, Unis, produced a disappointing litter of only one pup, a normal female in apparent good health. The reasons for this unusually small litter are unclear, but several factors may have been involved, including: first litter, young male, reabsorption of one or more fetuses. Since no litter-mate is available to serve as a control in the collection of experimental data, the single female pup will be utilized as a pilot subject for development of suitable mimicry training procedures. Special efforts have been made to assure successful conceptions in all subsequent matings (including artificial insemination), and litters of normal size are anticipated.

The following table presents a summary of the current experimental status of each dog:

TABLE I.

CURRENT EXPERIMENTAL STATUS

ANIMAL	CURRENT TRAINING STIMULUS	BREEDING STATUS
Calamity Jane	M-16 (buried in sand, 2")	Pregnancy confirmed.
Cher	Discontinued	———
Curly	Comp. B., 30 gms.	Not yet in heat.
Delilah	Comp. B, 30 gms.	Bred, pregnancy uncertain.
Gypsy	Comp. B, 20 gms. (ready to advance to M-16).	Bred, too early for pregnancy confirmation.
Topsy	M-16 (buried in sand, 1/2")	Bred, too early for pregnancy confirmation.
Unis	Comp. B, 20 gms. (Ready to advance to M-16).	Whelped, one female pup.
Zero	Comp. B, 30 gms.	Bred, too early for pregnancy confirmation.

Although the overall pace of an experimental program involving the breeding and study of successive litters is tempered by the unalterable time course of natural biological cycles, progress achieved to date in the present investigation is regarded as satisfactory. Future project objectives include (a) continued detection training of parent animals, (b) successful whelping of approximately six litters of pups, and (c) execution, analysis, and interpretation of the split-litter mimicry training experiments described previously. It is recommended that the investigation of animal progeny be pursued for several generations with a view toward improvements in stability of performance and training efficiency consistent with long range military objectives for mine/booby-trap biodetector systems.

CONCLUSIONS AND RECOMMENDATIONS

Experience gained in the execution of the work described in this report has served to demonstrate without a doubt that animals of various species can function effectively as biosensors for explosives. Detection accuracy exceeding ninety per cent has been demonstrated both for canines and exotic animal species. However, in the course of the research described, it has become evident that substantial additional attention needs to be directed towards evaluation of the following factors which exert considerable potential impact upon performance of the biosensors:

(1) Motivation

While results of the feasibility study demonstrate conclusively that the various animals investigated do indeed possess the olfactory acuity to detect buried mines (whether encased in metal, plastic, or wood) at depths of 6 inches or greater, their performance tends to be cyclical. That is, whereas on a given day the correct detection rate may approach perfection, on other days the animal may literally refuse to work effectively at the detection task. For presently unexplained reasons, his motivation to perform is curtailed with the result that mines which ordinarily would have been detected by the animal are ignored. His performance for that particular period then must be categorized as unreliable. To be of maximum value to the soldier in the field, biodetectors must be consistently reliable and willing to work each and every day with a high degree of proficiency. Thus, training procedures currently in use in preparing biosensors for mine detection need to be revised to assure production of detector dogs with not only (a) detection skills but also (b) motivation required to sustain a consistently high level of accurate detection over an extended time period under varied and arduous conditions of terrain and climate.

(2) Memory Effects

Previous research has also brought out that the biosensor animals invariably possess an exceptional memory such that, with a minimal number of trials, the animal is able, in many cases, to apparently commit the precise location of targets to memory. On subsequent runs, he then relies on his memory rather than olfactory acuity to direct

his detection endeavors. This phenomenon has been observed even though the animal runs the trail in reverse order, from end point to starting point, or starts his search at a midpoint in the trail instead of the customary start point. Thus, the contribution of memory to the biodetector's total correct detection score needs to be assessed by having them run a substantial number of mine trails with which they are totally unfamiliar. This is of critical importance since, in operational situations, the biodetector will typically be required to perform over unfamiliar territory. The extent of the contribution of the memory factor to the correct detection scores previously recorded for the biodetectors should be accurately appraised, so that an objective appraisal of their true ability to detect mines buried in unfamiliar terrain can be assessed. This could be accomplished by laying a substantial number of mine trails in numerous types of terrain and climates, using a variety of mines to be used only once for a given biodetector. The resultant data could then be compared statistically with the aggregate data collected to date for the biodetectors where the biodetector ran a mine trail more than once. Such statistical analysis would permit assessment of the extent to which the biodetector's memory (as opposed to olfactory skill) may have affected his correct detection "score."

It is recommended that additional attention be provided the above areas, using a larger sample size. The sample size used both for the various canine breeds and exotic animal species was exceedingly small--many times consisting of only one animal. This severely limits the degree of assurance with which one can make generalizations concerning the efficacy, in terms of detection capability, of specific breeds of dogs or specific animal species.